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Measurement of rotation angle of a small mobile robot by measuring surface potential of insulators

Takeshi Inoue[1], Hidetoshi Miyata[1], Akihiro Torii[1], Suguru Mototani[1], Kae Doki[1]

[1]Aichi Institute of Technology, Japan

v23701vv@aitech.ac.jp

Abstract

The authors are developing a compact equilateral triangle-shaped mobile robot using piezoelectric elements and electromagnets. The robot consists of an equilateral triangle with electromagnets at the apexes and piezoelectric elements at the sides. The robot operates by controlling the timing of the attraction and release of the electromagnets and extension and contraction of the piezoelectric elements. The robot moves in three directions (x, y, and θ). We used a desktop measurement system to measure the robot's rotation angle and provided feedback to the robot to follow a reference route. Previously, the rotation angle was measured by means of displacement measurements of electromagnets with three laser displacement sensors. In this paper, we propose a method to measure the rotation angle by measuring the surface potential of an insulator plate with a DC power supply connected to its sides. By measuring the potential difference at the vertices of an equilateral triangular robot, the rotation angle is determined by geometrical analysis. This method, which is unlike the laser encoder method, does not require communication with external devices since the sensor is mounted on the robot. Therefore, this method can contribute to an autonomous movement of the robot. By measuring the potential difference at the vertices of an equilateral triangular robot, it becomes possible to measure the rotation angle. Therefore, it can contribute to autonomous movement of the robot. In addition, by applying a high electric field to the insulator plate, high sensitive rotation angle measurement can be achieved, and therefore the measurement resolution can be improved.

Piezo-electric, inchworm, surface potential, measurement systems

1. Introduction

We have been developing inchworm actuators that can be applied to positioning and motion devices [1]. Many research groups have developed various types of inchworms [2]. The unique feature of the inchworm we have developed is that it does not have a guiding mechanism. The inchworm incorporates an electromagnet for clamping and a piezoelectric actuator (piezo) for movement. The disadvantage of the inchworm, however, is that it tends to follow a path that deviates from the target path. Reference [1] used a laser displacement meter to correct the angle. However, the method using a laser displacement meter requires communication with an external device, which hinders the autonomous operation of the actuator. Therefore, this paper proposes a method to measure the rotation angle of an inchworm-type moving mechanism by detecting the potential difference between the surface potential of an insulating plate with a DC power supply connected to its side and a needle-shaped electrode placed at each vertex of the inchworm. We also propose a method to perform angle compensation from the detection results.

2. Inchworm

Figure 1 shows the inchworm actuator we are developing. This actuator has a delta-shaped structure with three electromagnets at the apex of a triangle and three piezos on both sides of the triangle. Electromagnets are positioned perpendicular to the direction of piezoelectric expansion and contraction. The position of the actuator is defined from the position of the electromagnets as measured by a laser displacement sensor.

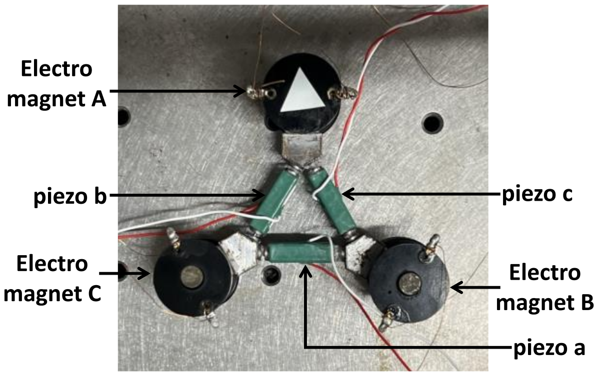

Figure 1. Inchworm

2.1. Linear motion of Inchworm

Figure 2 shows the principle of linear motion of the actuator. In Fig. 2(1), electromagnets B and C are excited. In Fig. 2(2), the applied voltage causes piezos B and C to elongate and attract the magnetic floor. This excitation causes the unexcited electromagnet A to move in the Y direction. At Fig. 2(3), electromagnets A and C are excited and attracted to the magnetic floor, while electromagnet B remains unexcited and piezo c contracts, causing electromagnet B to move. In Fig. 2(4), electromagnets A and B are excited and attracted to the magnetic floor, electromagnet C remains unexcited and piezo b contracts. This causes electromagnet C to move. The sequence Fig. 2(1)~Fig. 2(4) is repeated to propel the inchworm actuator.

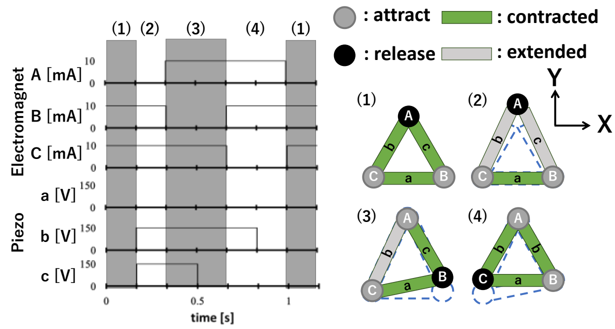

Figure 2. Control signals and principle of operation for straight-line motion

2.2. Angular motion of inchworm

Figure 3 shows the control signal and principle of operation for angular motion. In Fig. 3(1), electromagnets A and B are excited and electromagnet C is de-energized. At this time, voltage is applied to piezo b, and piezo b is extended. In Fig. 3(2), electromagnets A and B are kept excited and electromagnet C is kept de-energized. Piezo a is extended. At this time, electromagnet C moves in the direction of the combined force of the contraction direction of piezo b and the extension direction of piezo a. In Fig. 3(3), electromagnets A and C are excited and electromagnet B is de-energized. At this time, voltage is applied to piezo a to keep it extended. In step Fig. 3(4), electromagnets A and C are excited and electromagnet B is de-energized. The application of voltage to piezo a is stopped, and voltage is applied to piezo c. At this time, electromagnets A and C is in a state of extension, and electromagnet B is de-energized. At this time, electromagnet B moves in the direction of the combined force of the contraction direction of piezo a and the extension direction of piezo c. In Fig. 3(5), electromagnets B and C are excited and electromagnet A is de-energized. At this time, voltage is applied to piezo c to keep it extended. In Fig. 3(6), electromagnets B and C are excited and electromagnet A is de-energized. The voltage application to piezo c is stopped, and voltage is applied to piezo b. At this time, electromagnet B is in a state of excitation, and piezo b is in a state of extension. At this time, electromagnet A moves in the direction of the combined force of the contraction direction of piezo c and the extension direction of piezo b. By repeating the operation Fig. 3(1)~Fig. 3(6), the inchworm rotates around its center of gravity in the direction of the +C axis. The voltage amplified to three piezos are determined by V_{BC}, which is amplified and is applied to the three piezos.

3. Angle sensing by surface electric potential

The angle sensing of the moving mechanism proposed in this paper uses the electric potential generated on the surface of an insulator with electrodes on its sides. When the electrodes are parallel plates, the potential is uniformly distributed because the electrolysis between the plates is uniform. Figure 4 shows the angle detection system proposed in this paper. From the potential distribution generated on the surface of the insulator, the potential difference between the electrodes is detected by a differential potential measurement sensor using needle-shaped electrodes placed at each vertex of the Inchworm. The potential difference V at each vertex is determined by the electric field E applied to the insulator, the length l of one side of the inchworm, and the angle θpiezo between one side and the equipotential line. This method does not require communication with an external device because the angle is detected by a sensor mounted on the inchworm.

$$V = El\sin\theta_{piezo} \tag{1}$$

Figure 5 shows the potential difference between each vertex when l is 6 mm and E is 0.1 V/mm. In this study, the angle θ between the direction of the electric field and the direction of the inchworm was set to 0°, 30°, 45°, and 60°, and the voltage applied to the piezo was varied to operate the inchworm.

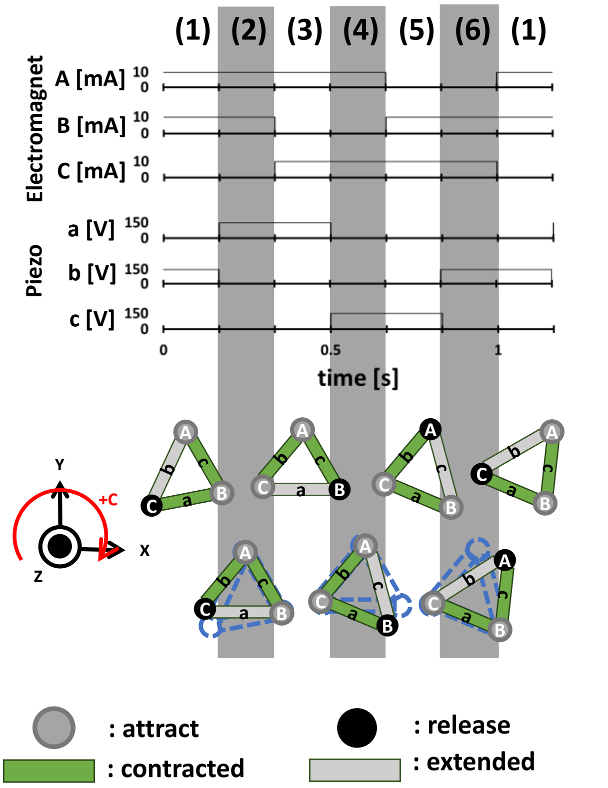

Figure 3. Control signals and principle of operation for rotational motion

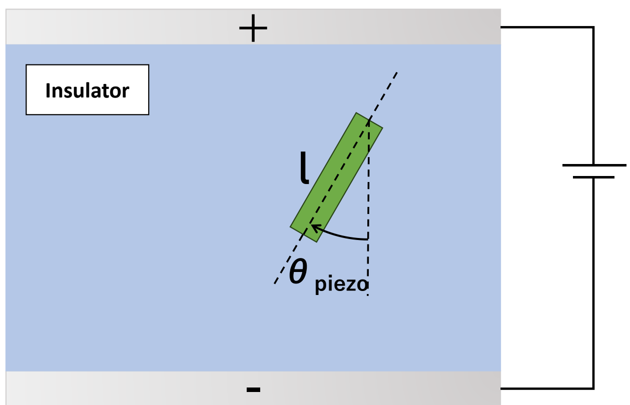

Figure 4. Potential difference between vertices at each angle

Table 1 shows the voltage between the vertices at each angle. The orientation of the inchworm varies the electric potential difference of the verteices of the triangle. The sum of the three potential differences equals zero in all four cases. The potential difference is determined by the electric field. In this case, the electric field is defined as 0.1 V/mm. The analytical error is not easily estimated. However, the measurement error of the potential difference is approximately 10 mV which corresponds to the measurement error.

Table 1 Potential difference between vertices at each angle

	Electric potential difference [V]		
	V_{AB}	V_{BC}	V_{CA}
0 °	5.20	0.00	-5.20
30 °	3.00	3.00	-6.00
45 °	1.55	4.24	-5.80
60 °	0.00	5.20	-5.20

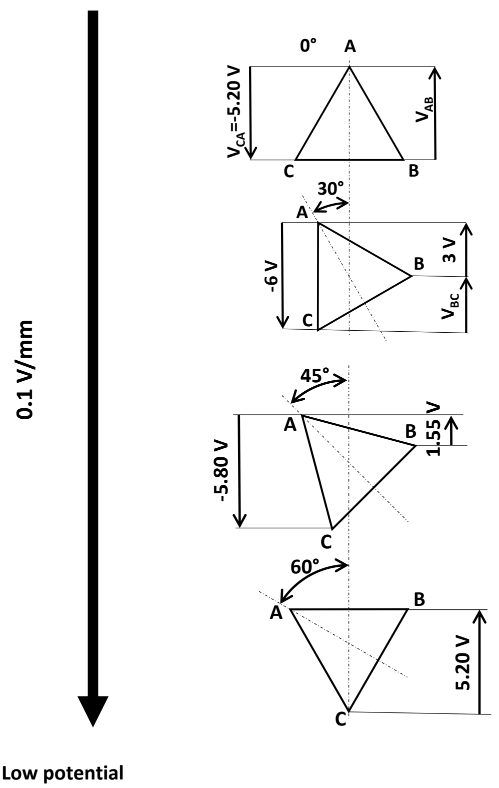

Figure 5. Potential difference between vertices at each angle

4. Angle compensation for inchworms

The potential difference between each vertex of the inchworm is amplified by an amplifier, and the voltage is given to the piezoelectric element of the inchworm to control piezoelectric elongation and correct the angle. Angle correction is performed by controlling the magnitude of the applied voltage to the piezos in the linear motion in Chapter 2. Voltage amplified by V_{AB} is applied to piezos c and voltage amplified by V_{CA} is applied to piezos b. If $|V_{AB}| < |V_{CA}|$, the elongation of the piezo is piezo c < piezo b. This causes the inchworm to deviate to the right toward the direction of travel. If $|V_{CA}| < |V_{AB}|$, piezoelectric elongation is piezoelectric b< piezoelectric c. This causes the inchworm to move leftward in the direction of travel.

5. Experimental Methods and Results

This time, the angle θ between the electric field and the perpendicular bisector between B and C in Fig. 2 is assumed, and the angle correction operation is performed by applying a potential difference with reference to Equation (1). The potential difference in Table 1 is given to the differential amplifier circuit, amplified by the amplifier as a signal, and applied to the piezo. In linear motion, the voltage amplified by V_{CA} is applied to piezo b, and the voltage amplified by V_{AB} is applied to piezo c. In linear motion, the voltage amplified by V_{CA} is applied to piezo b, and the voltage amplified by V_{AB} is applied to piezo c. The voltage applied to each piezo in rotational motion is the amplified voltage of V_{BC}.

The behavior of the inchworms with compensation is shown in Fig. 6. The inchworm is placed in four orientations, such as 0°, 30°, 45°, and 60°. Figure 6 shows the case of 60°. The original position of the inchworm is bottom right, and the voltage applied to piezo c, which is in proportional to V_{AB}, and piezo b, which is in proportional to V_{CA}, is bottom left in Fig. 6. The target orientation of the inchworm is 0° shown at the top in Fig. 5. In case of Fig. 6, the inchworm moves in the linear direction drawn with a dot-dash line, and its orientation changes according to different voltage applied to piezo c and piezo b. In case of Fig. 6, the voltage applied to piezo b is larger than that to piezo c and the inchworm rotates in the clockwise direction.

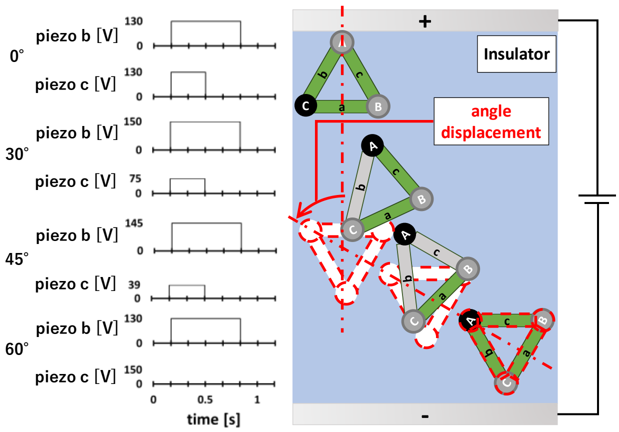

Figure 6. Angle compensation operation in straight-line operation

The angular displacement of the inchworm is measured by measuring the displacement of the Y-axis of electromagnets B and C. The inchworm is driven at 1 Hz. Figure 7 shows the angular displacement per cycle for the linear motion. Figure 8 shows the angular displacement per cycle for the rotational motion. The parameters are the original rotational angle of the inchworm.

Figure 7 shows the angle displacement of the inchworm from the original angle position. The angle displacement per one cycle at 60° and 45° is larger than that at 0°and 30°, due to the greater difference in voltage applied to piezo b and piezo c, as shown in Fig. 6.

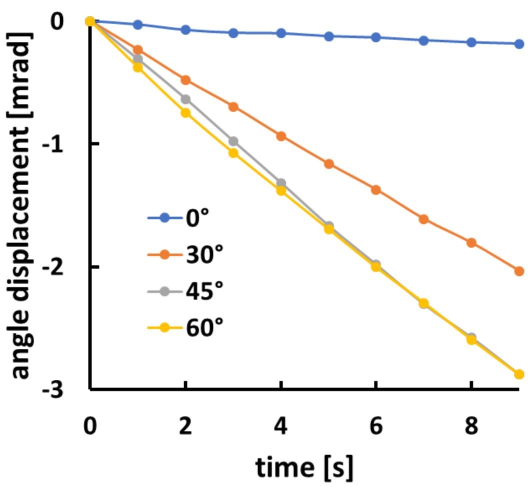

Figure 7. Angular displacement in straight-line motion

Figure 8 shows the angle displacement of the inchworm from the original angle position. The target orientation is 0°, as shown at the top in Fig. 5. The voltage applied to three piezos of the inchworm is determined by the potential difference V_{BC}, which is amplified by the drive circuit. The larger the original rotational position is, the greater the angle displacement per cycle is. This corresponds to the rotational speed being relative to the rotational position.

Table 2 shows the average angular displacements for the straight-line and rotational movements. The inchworm moves in the direction of θ closer to 0°. The displacement speed in the rotational motion of the inchworms was increased by increasing the voltage applied to the piezo in the rotational motion.

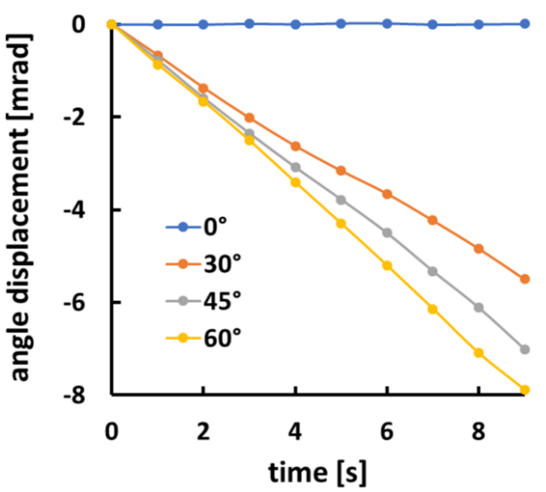

Figure 8. Displacement angle in rotational motion

Table 2 Displacement angle for each cycle

	angle displacement [mrad]	
	straight-line	rotation
0 °	-0.02	0.00
30 °	-0.22	-0.61
45 °	-0.32	-0.78
60 °	-0.32	-0.88

7. Conclusions

In this paper, we proposed a method to detect the angle of inchworms from the surface potential of an insulating plate with electrodes attached to its sides, and to perform angle compensation by analogously controlling the voltage applied to the piezo. The larger the phase between the target angle and the inchworm, the larger the displacement angle during operation, and the smaller the displacement angle became as the direction of the inchworm approached the target angle.

Acknowledgement

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References

[1] Torii A, Mitsuyoshi Y, Mototani S, and Doki K, 2018 *Int. J. of Automation Technology*, **Vol. 12**, No. 5, pp.784-790

[2] Li j, Huang H, Morita T, *Sensors and Actuators A: Physical,* **Vol. 292**, pp. 39-51, 2019