

## *Retraction*

# **Retracted: Static Characteristics of a Linear Bipotentiometer Sensor**

### **Security and Communication Networks**

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

### **References**

- [1] C. Chen, Y. Cai, T. Fan, and P. He, "Static Characteristics of a Linear Bipotentiometer Sensor," *Security and Communication Networks*, vol. 2021, Article ID 9958652, 9 pages, 2021.

## Research Article

# Static Characteristics of a Linear Bipotentiometer Sensor

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In this paper, the structure and the working principle of an existing linear potentiometer sensor are introduced; furthermore, the structure and circuit connection method of a new linear bipotentiometer sensor is proposed. The sensitivity, step error, and load characteristics of the existing potentiometer sensor and the linear bipotentiometer sensor are both studied and compared. The simulation results of their static characteristics show that the sensitivity of the linear bipotentiometer sensor is increased, the relative load error is greatly reduced, and the linearity is improved. Meanwhile, the measurement accuracy of the linear bipotentiometer sensor is effectively improved.

## 1. Introduction

A sensor is a device that can sense the needed signal and convert it into an available output signal according to certain rules [1–3]. The sensor is the key part of the measurement in control systems [4, 5]. If the sensor accuracy is not high and the dynamic performance is poor, the whole system will be difficult to operate normally. Therefore, the working reliability, static precision, and dynamic performance of the sensor are the most basic indexes [6].

A linear potentiometer sensor is a kind of resistance sensor, which can be used to measure pressure, displacement, acceleration, and other parameters [7, 8]. An existing linear potentiometer sensor is composed of a linear potentiometer, which has the advantages of simple structure and large output signal, but its load error is relatively large and linearity is relatively poor, especially when the detection input is in the half range, its load error is the largest, and it is difficult to achieve high precision measurement [9, 10]. In order to improve this shortcoming, the load characteristic of the potentiometric displacement sensor is automatically compensated by a general-purpose integrated operational amplifier and an integrated voltage regulator in the paper [11]. In [12], the nonlinear errors are lowered by a magnetic

levitation control system and an aerostatic bearing device in the vertical and horizontal directions.

In order to improve the application performance of the existing linear potentiometer sensor, many methods are proposed [13–15], and some of them are effective. In this paper, based on an existing linear potentiometer sensor, a new scheme of a linear bipotentiometer sensor is proposed, the sensitive part of which is composed of two identical linear potentiometers. Under the same measuring conditions, some static characteristics of both the existing linear potentiometer sensor and the linear bipotentiometer sensor are studied, simulated, analyzed, and compared, and the conclusion of the linear bipotentiometer sensor is drawn. The static characteristics of the linear bipotentiometer sensor are improved, the relative load error is reduced, and the measurement accuracy is improved.

The main contributions of this paper focus on the following three aspects:

- (i) A new linear bipotentiometer sensor is designed relative to the existing linear potentiometer sensor.
- (ii) Some static characteristics of the linear bipotentiometer sensor are studied relative to the existing linear potentiometer sensor.

- (iii) The static characteristics of the two kinds of sensors are simulated, and the conclusion is drawn.

The linear bipotentiometer sensor is a kind of sensor with improved structure, which is based on the existing linear potentiometer sensor. From the layout point of view, in this paper, firstly, the principle of the linear potentiometer is introduced, so is the circuit connection of the existing linear potentiometer sensor, which leads to the structure and circuit connection of the linear bipotentiometer sensor. Then, some static characteristics of the linear bipotentiometer sensor are analyzed and compared with the existing linear potentiometer sensor. Finally, numerical simulation of their static characteristics is carried out, and a conclusion is drawn.

The rest of the paper is organized as follows. Section 2 gives structures of a linear bipotentiometer sensor and an existing linear potentiometer sensor. On the basis of the sensor structure described above, the sensitivity, step error, and load characteristics of the existing linear potentiometer sensor and the linear bipotentiometer sensor are studied in Section 3. For verifying the theoretical results, numerical simulations are given in Section 4. At last, conclusions are presented in Section 5.

## 2. Structure of a Linear Bipotentiometer Sensor

A linear potentiometer sensor is a kind of resistance sensor that converts the change of measured physical quantity into the change of resistance value, which is to transform the mechanical linear displacement or angular displacement into a corresponding resistance output.

**2.1. Linear Potentiometer.** The linear potentiometer is the sensitive component of the linear potentiometer sensor. The schematic diagram of the linear potentiometer is shown in Figure 1.

The linear potentiometer is made of resistance wire regularly and neatly wound on an insulated framework, and the resistance wire is very thin, and its resistance coefficient is very high. The resistance wire is alloy resistant with surface insulation. The insulating layer on the surface of the resistance wire is removed and polished to form a contact point, where the brush can slide on it smoothly. A sliding arm and an electric brush on it are moved along the potentiometer. The cross section of the framework is equal everywhere, and the distance between the resistance coils is equal. The structure diagram of the linear potentiometer is shown in Figure 2; then, it can be concluded that

$$\begin{cases} R_x = \frac{x}{L}R_{\max}, \\ R_{\max} = \frac{2(b+h)np}{A}, \\ n = \frac{L}{t}, \end{cases} \quad (1)$$

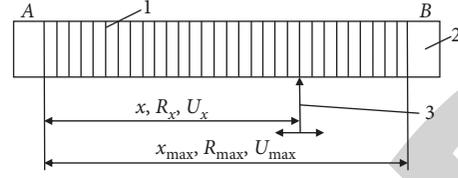


FIGURE 1: Schematic diagram of linear potentiometer sensor. (1) Resistance wire. (2) Insulated framework. (3) Sliding arm.

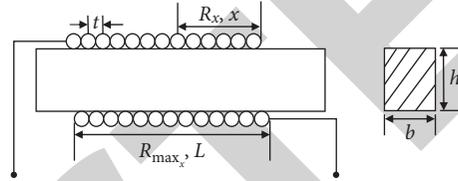


FIGURE 2: Structure diagram of the linear potentiometer.

where  $R_{\max}$  is the total resistance of the potentiometer, the distribution of which along the length is uniform, and the total length of which is  $L$ .  $x$  ( $0 < x < L$ ), which is the length of brush movement,  $R_x$  is the resistance value corresponding to the brush movement  $x$ ,  $b$  and  $h$  are the width and height of the framework, respectively,  $A$  is the cross-sectional area of the wire, the resistivity of which is  $\rho$ , the total number of winding turns of the potentiometer is  $n$ , and  $t$  is the distance between the resistance coils.

### 2.2. Principle of an Existing Linear Potentiometer Sensor.

An existing linear potentiometer sensor is composed of a linear potentiometer, and its circuit connection is shown in Figure 3.

In Figure 3,  $R_L$  is the load resistance value, which may be the internal resistance of the display instrument, the input resistance of the amplifier circuit, or other loads.  $U_i$  is the input voltage of the sensor.  $U_{o1}$  is the output voltage of the existing linear potentiometer sensor.

### 2.3. Structure and Principle of a Linear Bipotentiometer Sensor.

The sensing element of a linear bipotentiometer sensor is composed of two identical linear potentiometers. These two potentiometers share one sliding arm, and there is an electric brush at each end of the sliding arm. The two brushes move on the two potentiometers with equal displacement at the same time; the resistance changes uniformly with the brush displacement; and the structure diagram of the linear bipotentiometer sensor is shown in Figure 4. The two sides of the brush are not conductive, and the two ends of the output voltage are led out from both sides of the brush; its specific circuit connection is shown in Figure 5, where  $U_{o2}$  is the output voltage of the linear bipotentiometer sensor, which is the output voltage from the two brush ends after the brush is shifted.

In the process of brush sliding, it can be concluded that

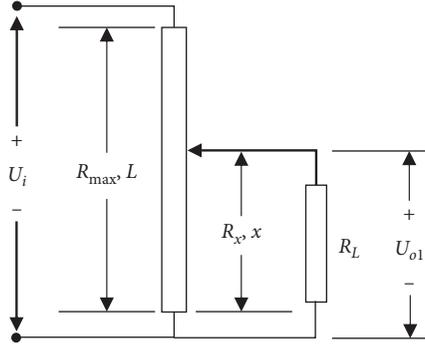


FIGURE 3: Circuit connection diagram of an existing linear potentiometer sensor.

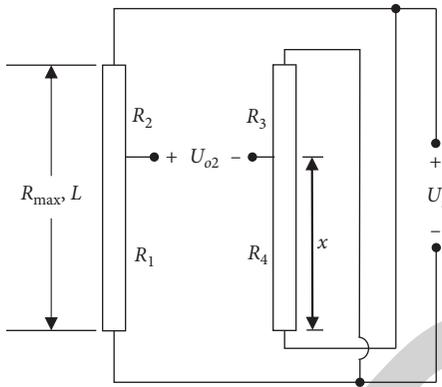


FIGURE 4: Structure diagram of a linear bipotentiometer sensor.

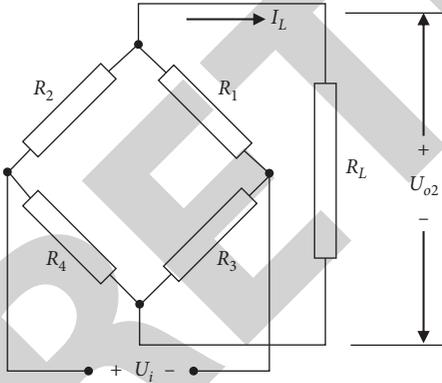


FIGURE 5: Circuit connection diagram of a linear bipotentiometer sensor.

$$\left\{ \begin{array}{l} R_1 = R_4 = \frac{x}{L}R_{\max}, \\ R_2 = R_3 = \left(1 - \frac{x}{L}\right)R_{\max}, \\ R_1 + R_2 = R_{\max}, \\ R_3 + R_4 = R_{\max}. \end{array} \right. \quad (2)$$

### 3. Static Characteristic Analysis of the Linear Potentiometer and Bipotentiometer Sensors

The research content of a kind of sensor includes many aspects, mainly including the basic characteristics, working principle, calibration, and interference factors of the sensor. The basic characteristics of the sensor include static and dynamic characteristics and also many specific characteristic indexes. The partial relationship is shown in Figure 6. In this paper, the linear bipotentiometer sensor is a new structure potentiometer sensor compared with the existing linear potentiometer sensor; therefore, only the static characteristics different from the existing linear potentiometer sensor are studied, that is, the contents in the red box in Figure 6.

**3.1. No-Load Characteristic.** As shown in Figure 3, when the load resistance  $R_L \rightarrow \infty$ , i.e., no load, the output voltage  $u_{o1}$  of the brush sliding from the initial position to  $x$  is as follows:

$$U_{o1} = U_i \frac{R_x}{R_{\max}} = \frac{x}{L}U_i. \quad (3)$$

When  $x$  changes from 0 to  $L$ , the range of the output voltage  $U_{o1}$  is  $[0, U_i]$ .

In Figure 5, when the load resistance  $R_L \rightarrow \infty$ , i.e., no load, the output voltage  $u_{o2}$  of the brush sliding from the initial position to  $x$  is as follows:

$$\begin{aligned} U_{o2} &= \frac{(x/L)R_{\max} - (1 - (x/L))R_{\max}U_i}{R_{\max}} \\ &= U_i \left( \frac{R_1}{R_{\max}} - \frac{R_3}{R_{\max}} \right) = \left( \frac{2x}{L} - 1 \right)U_i. \end{aligned} \quad (4)$$

When  $x$  changes from 0 to  $L$ , the range of the output voltage  $U_{o2}$  is  $[-U_i, U_i]$ .

According to the above analysis, the no-load output voltage range of the linear bipotentiometer sensor is twice that of the existing linear potentiometer sensor.

**3.2. Sensitivity.** The static sensitivity is defined as the ratio of the change of the output of the sensor to the change of the input that causes the change of the output [3]. For the existing linear potentiometer sensor, in the whole path of brush movement, the output voltage variation range  $\Delta U_1$  is as follows:

$$\Delta U_1 = \frac{L}{L}U_i - \frac{0}{L}U_i = U_i. \quad (5)$$

Its voltage sensitivity  $S_{v1}$  is as follows:

$$s_{v1} = \frac{\Delta U_1}{\Delta x_{\max}} = \frac{U_i}{L}. \quad (6)$$

For the linear bipotentiometer sensor, in the whole path of brush movement, the output voltage variation range  $\Delta U_2$  is as follows:

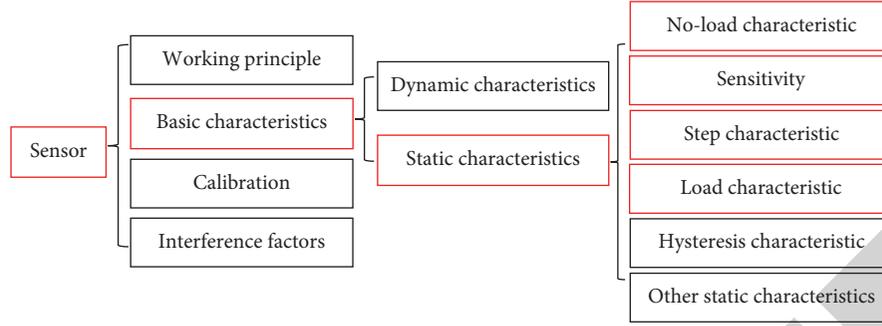


FIGURE 6: Relationship diagram of partial research content of sensor.

$$\Delta U_2 = \left(\frac{2L}{L} - 1\right)U_i - \left(\frac{0}{L} - 1\right)U_i = 2U_i. \quad (7)$$

Its voltage sensitivity  $S_{v2}$  is as follows:

$$S_{v2} = \frac{\Delta U_2}{\Delta x_{\max}} = \frac{2U_i}{L}. \quad (8)$$

The above analysis shows that the voltage sensitivity of a linear bipotentiometer sensor is twice that of the existing linear potentiometer sensor. That is,

$$S_{v2} = 2S_{v1}. \quad (9)$$

**3.3. Step Characteristic, Voltage Resolution, and Step Error.** According to the structure of the potentiometer sensor, the output voltage will jump one step when the brush moves one turn of the coil; the relationship between the output voltage curve of the sensor and the movement of the brush is shown in Figure 7.

When the brush moves one turn of the coil, the change of resistance is  $\Delta R$ , that is,

$$\Delta R = \frac{R_{\max}}{n}, \quad (10)$$

and the output voltage variation caused by it is called apparent resolution pulse  $\Delta U_n$ , that is,

$$\Delta U_n = \frac{U_i}{R_{\max}} \times \Delta R = \frac{1}{n}U_i. \quad (11)$$

When the brush moves between the two adjacent turns (the  $j$  and  $j+1$  turns), the two adjacent turns will be short-circuited, which makes the total turns of linear potentiometer sensor become  $n-1$  turns. At this time, the output voltage will have a small jump  $\Delta U_b$ , that is,

$$\Delta U_b = u_i \left( \frac{1}{n-1} - \frac{1}{n} \right). \quad (12)$$

Therefore, the apparent resolution pulse is composed of two steps of different sizes. The large step is regarded as the main resolution pulse  $\Delta U_a$ , and the small step is regarded as the secondary resolution pulse  $\Delta U_b$ . It can be concluded that

$$\Delta U_n = \Delta U_a + \Delta U_b. \quad (13)$$

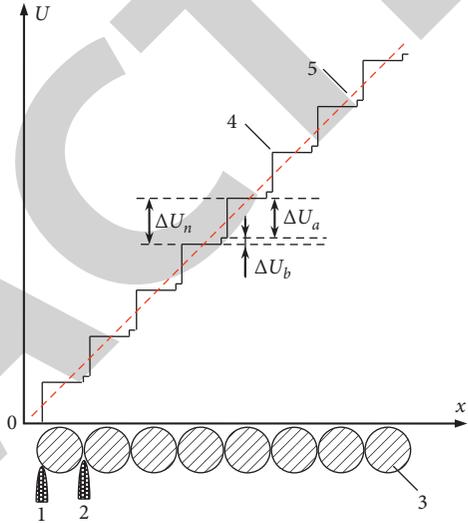


FIGURE 7: Actual step characteristic curve of linear potentiometer sensor.(1) The brush being in contact with a wire. (2) The brush being in contact with two wires. (3) Potentiometer wire. (4) Actual step characteristic curve. (5) Ideal characteristic curve.

For the existing linear potentiometer sensor, its apparent resolution pulse  $\Delta U_{n1}$  is as follows:

$$\Delta U_{n1} = \Delta U_{a1} + \Delta U_{b1} = \frac{U_i}{n}. \quad (14)$$

In Figure 7, the actual step characteristic is shown with real broken line; however, the ideal sensor output is shown by the red dotted line. The step characteristic curve fluctuates up and down around the ideal characteristic line, which results in a certain deviation and is called step error [8]. The step error of the linear potentiometer sensor is usually expressed as the percentage of the ratio between the maximum deviation of the actual step characteristic curve to the ideal characteristic line and the output voltage variation range. That is,

$$\begin{aligned} \gamma_{n1} &= \frac{\pm ((1/2)\Delta U_{n1})}{\Delta U_1} \times 100\% \\ &= \pm \frac{(1/2)U_i}{\Delta U_i} \times 100\% \\ &= \pm \frac{1}{2n} \times 100\%. \end{aligned} \quad (15)$$

Voltage resolution is defined as the percentage of the ratio between the maximum value voltage step of the potentiometer and the maximum output voltage range within the whole path of the brush movement. For the existing linear potentiometer sensor, the voltage resolution is as follows:

$$e_{n1} = \frac{\Delta U_{n1}}{\Delta U_1} \times 100\% = \frac{(U_i/n)}{U_i} \times 100 = \frac{1}{n} \times 100\%. \quad (16)$$

For the linear bipotentiometer sensor, its step characteristic curve is similar to the existing linear potentiometer sensor, and its apparent resolution pulse, step error, and voltage resolution are as follows:

$$\begin{aligned} \Delta U_{n2} &= \left( \frac{R_1 + \Delta R}{R_{\max}} - \frac{R_3 - \Delta R}{R_{\max}} \right) U_i \\ &\quad - \left( \frac{R_1}{R_{\max}} - \frac{R_3}{R_{\max}} \right) U_i \\ &= \frac{2}{n} U_i, \\ \gamma_{n2} &= \frac{\pm ((1/2)\Delta U_{n2})}{\Delta U_2} \times 100\% \\ &= \pm \frac{(1/2)(2U_i/n)}{2U_i} \times 100\% \\ &= \frac{1}{2n} \times 100\%, \\ e_{n2} &= \frac{U_{n2}}{\Delta U_2} \times 100\% = \frac{(2U_i/n)}{2U_i} \times 100 = \frac{1}{n} \times 100\%. \end{aligned} \quad (17)$$

The above analysis shows that the apparent resolution pulse of the linear bipotentiometer sensor is twice that of the existing linear potentiometer sensor, and the step error and voltage resolution of the linear bipotentiometer sensor are equal to that of the existing linear potentiometer sensor. That is,

$$\begin{aligned} \Delta U_{n2} &= 2\Delta U_{n1}, \\ \gamma_{n2} &= \gamma_{n1}, \\ e_{n2} &= e_{n1}. \end{aligned} \quad (18)$$

In practical application, the ratio of brush diameter to wire diameter is 10, so the influence of step error can be ignored.

**3.4. Load Characteristic and Load Error.** If the output of potentiometer sensor is connected with load resistance, its output characteristic is called load characteristic.

For the existing linear potentiometer sensor, the circuit connected with load resistance  $R_L$  is shown in Figure 3: its load output voltage  $U_{L1}$  is as follows:

$$U_{L1} = \frac{R_x R_L}{R_L R_{\max} + R_x R_{\max} - R_x^2} U_i. \quad (19)$$

The input voltage and measurement range of many sensors from different manufacturers or models are different. For analysis and comparison, they are processed by removing dimensions.

Supposed relative variation of resistance is  $r$ , that is,

$$r = \frac{R_x}{R_{\max}}, \quad (20)$$

where  $r$  is defined as the relative change factor of displacement.

Let

$$m = \frac{R_{\max}}{R_L}, \quad (21)$$

where  $m$  is defined as the load factor.

Taking equations (1), (20), and (21) into equation (22), the load characteristic  $Y_1$  of the existing linear potentiometer sensor is obtained, that is,

$$Y_1 = \frac{U_{L1}}{U_i} = \frac{r}{1 + rm - mr^2}. \quad (22)$$

It can be seen from equation (22) that when the potentiometer is connected with a load resistor, the load characteristic of the existing linear potentiometer sensor is nonlinear, and the larger the load coefficient  $m$  is, the more serious it is.

The deviation between load characteristic and no-load characteristic is called load error. The load error of the existing linear potentiometer sensor is assumed to be  $\delta_{L1}$ . Then,

$$\delta_{L1} = U_{o1} - U_{L1}. \quad (23)$$

The load error can show how close the actual output of the sensor is to the ideal output, but it cannot show the measurement accuracy of different values, so the relative error is often used to show the accuracy of the measured value. Because the output voltage of the linear bipotentiometer sensor has positive, negative, and zero values, the relative load error is defined as the percentage of the ratio of the absolute load error to the output range of the sensor. For the existing linear potentiometer sensor, its relative load error  $\sigma_{L1}$  is as follows:

$$\sigma_{L1} = \frac{U_{o1} - U_{L1}}{\Delta U_1} \times 100\%. \quad (24)$$

For the linear bipotentiometer sensor, the circuit connected with load resistance  $R_L$  is shown in Figure 5; its load output voltage is as follows:

$$U_{L2} = \frac{(R_1 R_4 - R_2 R_3) R_L}{*} U_i, \quad (25)$$

where  $*$  =  $(R_1 + R_2)(R_3 + R_4)R_L + R_1 R_2 (R_3 + R_4) + R_3 R_4 (R_1 + R_2)$ .

The load characteristic expression  $Y_2$  of the linear bipotentiometer sensor can be obtained by taking equations (2), (20), and (21) into equation (24), i.e.,

$$Y_2 = \frac{U_{L2}}{U_i} = \frac{2r - 1}{1 + 2r(1 - r)m}. \quad (26)$$

According to the definition of load error, the load error  $\delta_{L2}$  of the linear bipotentiometer sensor is as follows:

$$\delta_{L2} = U_{o2} - U_{L2}. \quad (27)$$

According to the definition of the relative load error, the relative load error  $\sigma_{L2}$  of the linear bipotentiometer sensor is as follows:

$$\sigma_{L2} = \frac{U_{o2} - U_{L2}}{\Delta U_2} \times 100\%. \quad (28)$$

Based on the previous analysis of static characteristics, the four static characteristics are summarized as shown in Table 1.

#### 4. Numerical Simulation

In this section, MATLAB software is used to simulate the curves of two kinds of sensors of linear potentiometer under no-load and load conditions. Suppose the total length of the potentiometer  $L = 15$  cm, input voltage  $U_i = 5$  V, coil turn  $n = 750$ , pitch  $t = 0.2$  mm, and  $U_o$  is the output voltage when the brush moves to  $x$  ( $0 < x < 15$  cm).

The no-load output voltage is simulated according to equations (3) and (4), and the simulation curve is shown in Figure 8. It can be seen from Figure 8 that the relationship between input and output of the two linear potentiometer sensors is linear and is without nonlinear error. Therefore, the no-load voltage output curve is the ideal output curve of the sensor. The output range of the linear bipotentiometer sensor is twice that of the existing linear potentiometer sensor. Therefore, the linear bipotentiometer sensor increases the signal output of measured parameters, which is the result of increased sensitivity with identical measurement range.

When  $m = 0, 0.5, 2,$  and  $5$ , the load output voltage curve of the existing linear potentiometer sensor is simulated according to equation (19); the simulation curve family is shown in Figure 9. It can be seen from Figure 9 that the load output voltage curve of the existing linear potentiometer sensor is a droop curve, which indicates that the load output voltage is lower than the no-load output voltage, and the less the  $m$  value is, the closer the load output voltage curve is to the no-load curve ( $m = 0$ ).

When  $m = 0, 0.5, 2,$  and  $5$ , the load output voltage curve of the linear bipotentiometer sensor is simulated according to equation (25), and the simulation curve is shown in Figure 10. It can be seen from Figure 10 that the load output voltage curve of the linear bipotentiometer sensor has no

load error when the brush is in the middle position of the potentiometer. When the brush is located on both sides of the midpoint of the potentiometer, the load output voltage curve is distributed on both sides of the no-load output voltage curve.

When  $m = 0, 0.5, 2,$  and  $5$ , the load characteristic curve of the existing linear potentiometer sensor is simulated according to equation (22), and the simulation curve family is shown in Figure 11. It can be seen from Figure 11 that the load characteristic curve of the existing linear potentiometer sensor is a droop curve, which indicates that the load output voltage is lower than the no-load output voltage, and the less the  $m$  value is, the closer the load characteristic curve is to the no-load curve ( $m = 0$ ).

When  $m = 0, 0.5, 2,$  and  $5$ , the load characteristic curve of the linear bipotentiometer sensor is simulated according to equation (26), and the simulation curve is shown in Figure 12. It can be seen from Figure 12 that the load characteristic curve of the linear bipotentiometer sensor has no load error when the brush is in the middle position of the potentiometer. The load characteristic curve is distributed on both sides of the no-load characteristic curve when the brush is at both ends of the potentiometer.

When  $m = 0, 0.5, 2,$  and  $5$ , the load error curve of the existing linear potentiometer sensor is simulated according to equation (23), and the simulation curve family is shown in Figure 13. It can be seen from Figure 13 that the load error curve of the existing linear potentiometer sensor gets the largest value when the brush is in the middle position.

When  $m = 0, 0.5, 2,$  and  $5$ , the load characteristic curve of the linear bipotentiometer sensor is simulated according to equation (27), and the simulation curve is shown in Figure 14. It can be seen from Figure 14 that the load error curve of the linear bipotentiometer sensor is smaller or even zero when the brush is in the middle section of the potentiometer.

When  $m = 0, 0.5, 2,$  and  $5$ , the relative load error curve of the existing linear potentiometer sensor is simulated according to equation (24), and the simulation curve family is shown in Figure 15. It can be seen from Figure 15 that the relative load error curve of the existing linear potentiometer sensor gets the largest value when the brush is about two-thirds of the way position. When the larger the  $m$  value is, the larger the relative error of the brush in the same position is.

Finally, when  $m = 0, 0.5, 2,$  and  $5$ , the relative load error curve of the linear bipotentiometer sensor is simulated according to equation (28), and the simulation curve is shown in Figure 16. It can be seen from Figure 16 that the relative load error curve of the linear bipotentiometer sensor has positive and negative, and the relative load error is equal to zero when the brush is in the middle position, which is convenient to linearize the output signal of the sensor.

TABLE 1: Some static characteristics of the two kinds of sensors.

	Sensitivity	Step characteristic	No-load characteristic	Load characteristic
The existing linear potentiometer sensor	$s_{v1} = (U_i/L)$	$\gamma_{i1} = \pm (1/2n) \times 100\%$	$U_{o1} = (x/L)U_i$	$Y_1 = (r/1 + rm - mr^2)$
The linear bipotentiometer sensor	$s_{v2} = (2U_i/L)$	$\gamma_{i2} = \pm (1/2n) \times 100\%$	$U_{o2} = ((2x/L) - 1)U_i$	$Y_2 = ((2r - 1)/1 + 2r(1 - r)m)$
Relationship	$s_{v2} = 2s_{v1}$	$\gamma_{i2} = \gamma_{i1}$		

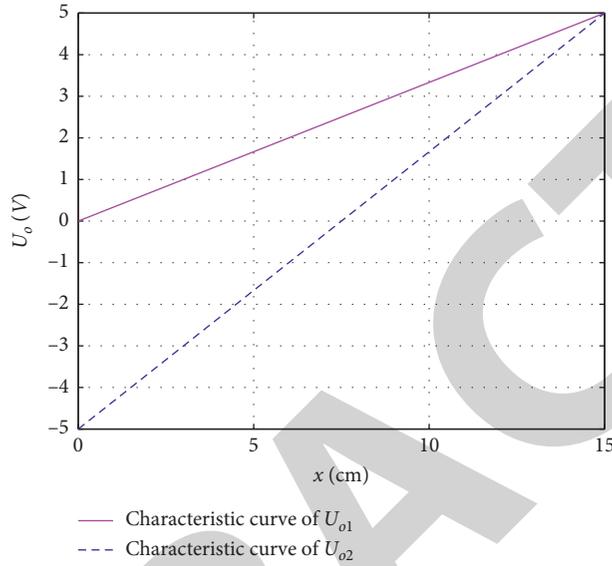


FIGURE 8: No-load output voltage curve of the two kinds of linear potentiometer sensors.

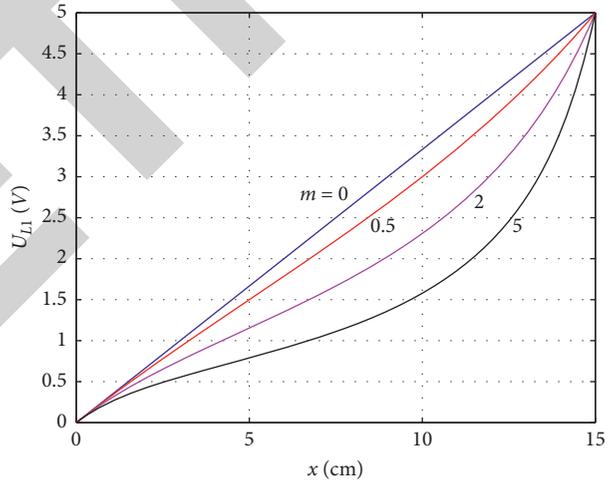


FIGURE 9: Load output voltage curve of the existing linear potentiometer sensor.

The no-load output voltage, load output voltage, load characteristic, and relative load error curve of two kinds of sensors are simulated and analyzed. Compared with the two

types of sensors, under the same conditions (the same as  $m$  and  $r$ ), the linearity of the linear bipotentiometer sensor is much better than that of the existing linear potentiometer

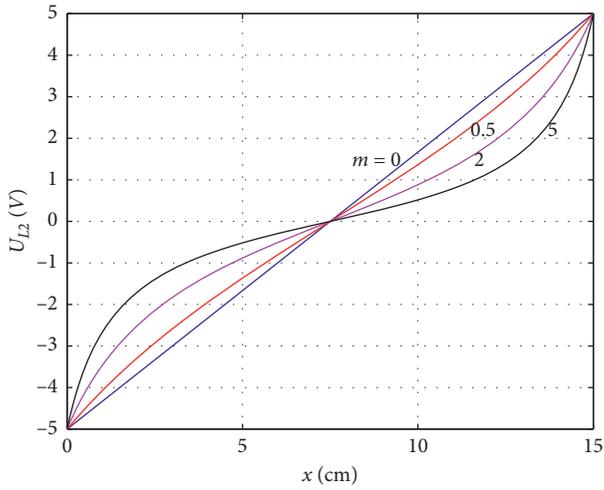


FIGURE 10: Load output voltage curve of the linear bipotentiometer sensor.

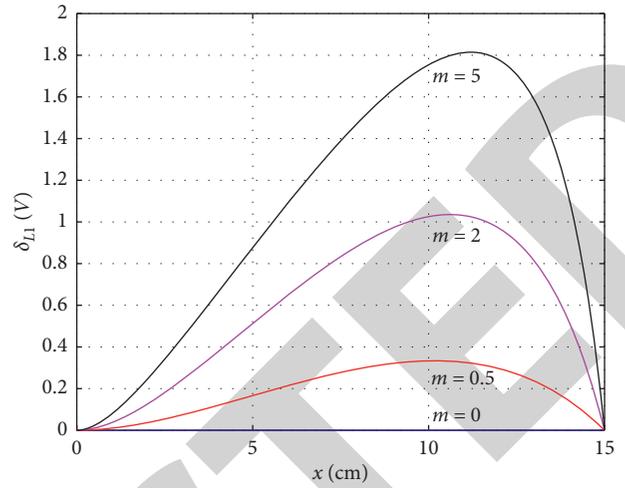


FIGURE 13: Load error curve of the existing linear potentiometer sensor.

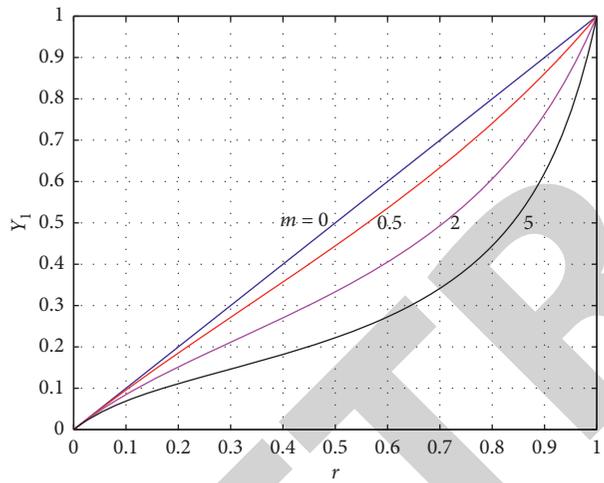


FIGURE 11: Load characteristic curve of the existing linear potentiometer sensor.

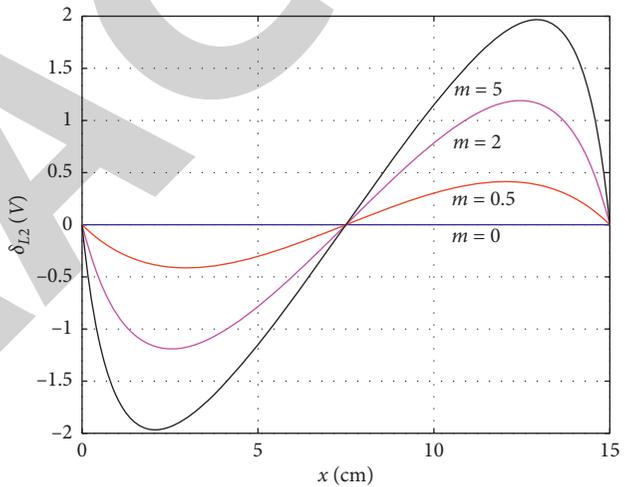


FIGURE 14: Load error curve of the linear bipotentiometer sensor.

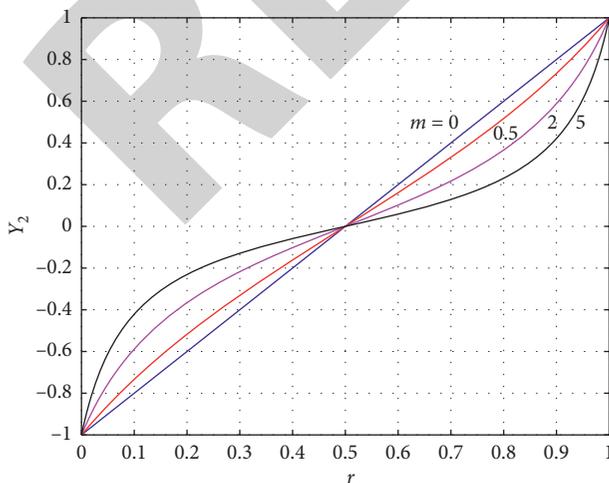


FIGURE 12: Load characteristic curve of the linear bipotentiometer sensor.

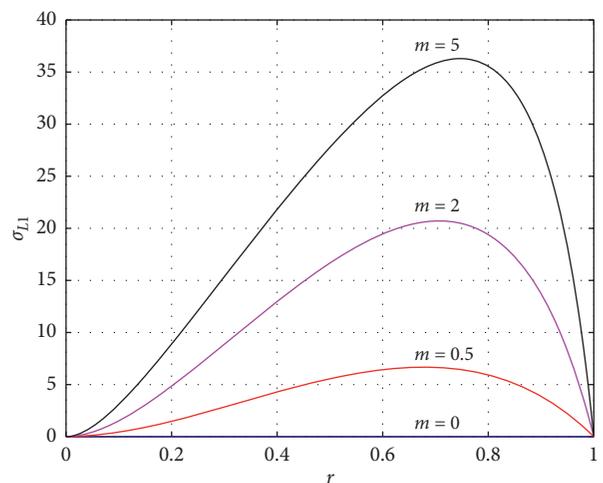


FIGURE 15: Relative load error curve of the existing linear potentiometer sensor.

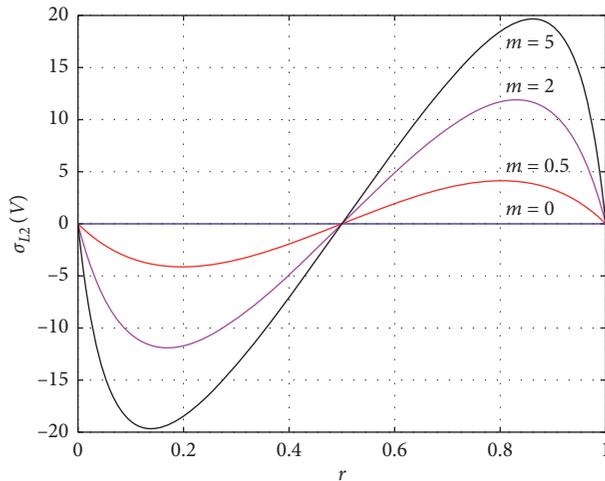


FIGURE 16: Relative load error curve of the linear bipotentiometer sensor.

sensor, and the relative load error curve of the linear bipotentiometer sensor is only half that of the existing linear potentiometer sensor. From the different values of  $m$ , the sensor is working in the case of less  $m$  value, that is, the load resistance of the sensor is much larger than that of the sensitive element. Compared with the existing linear potentiometer sensor, the measurement value of the middle part of the linear bipotentiometer sensor is more accurate. Hence, a theoretical basis is provided for the use of the linear bipotentiometer sensor.

## 5. Conclusions

In this paper, the linear bipotentiometer sensor is proposed by changing the structure of the existing linear potentiometer sensor; at the same time, its working principle and some static characteristics are studied in detail. Compared with the existing linear potentiometer sensor, the sensitivity of the linear bipotentiometer sensor is doubled, the no-load output voltage range is doubled, the relative load error is half, the step error is unchanged, and its linearity is improved, which has a certain application value.

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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## References

- [1] K. J. Xu, *Sensor and Detection Technology*, Electronic Industry Press, Beijing, China, 2016.
- [2] G. D. Luan, *Sensors and Their Applications*, Xidian University Press, Xinan, China, Third edition, 2018.
- [3] X. R. Gao, J. L. Li, and C. Y. Peng, *Sensor Technology*, Southwest Jiaotong University Press, Chengdu, China, 2nd edition, 2013.
- [4] J. Kang, "Application of MCU in inverted pendulum control system," *Mechanical Engineering & Automation*, vol. 186, no. 5, pp. 138–140, 2014.
- [5] Z. G. Yu, "Single chip microcomputer control system of laser engraving machine with membrane resistance," *Journal of Huzhou Vocational and Technological College*, vol. 3, pp. 14–18, 2015.
- [6] W. Guang, C. Ming, T. Xianchun, J. Xuerong, and X. Zhang, "Static characteristics and influencing factors analysis of azimuth axis of a radar antenna pedestal," *Journal of Physics: Conference Series*, vol. 1654, Article ID 012114, 2020.
- [7] X. J. Liu, J. Li, G. Zhao, and G. H. Liu, "Principle design and quantitative analysis of indicator for oil-fired light aircraft oil-volume-meter," *Journal of Shenyang Institute of Aeronautical Engineering*, vol. 15, no. 2, pp. 67–73, 1998.
- [8] J. Chen and H. Huang, *Sensor and Detection Technology*, Higher Education Press, Beijing, China, 2nd edition, 2010.
- [9] G. H. Qin and J. W. Lu, "A noise canceling method suitable for microprocessor based detecting instrument," *Electronic Measurement Technology*, no. 3, pp. 49–51, 1998.
- [10] H. Wu, S. Wang, Y. Xie, S. Chang, and Y. Zhao, "Design and characteristics of a new aerostatic bearing stylus sensor for surface measurement," *Measurement*, vol. 174, no. 2, Article ID 108996, 2021.
- [11] S. H. Zhou, "Automatic compensation for load characteristic of potentiometric displacement sensor," *Journal of Transducer Technology*, vol. 22, no. 2, pp. 45–47, 2003.
- [12] M. Numan, F. Subhan, W. Z. Khan et al., "A systematic review on clone node detection in static wireless sensor networks," *IEEE Access*, vol. 8, pp. 65450–65461, 2020.
- [13] J. F. Yu, "Optimization design of the transmission mechanism parameters for potentiometer transducer," *Measurement and Control Technology*, vol. 34, no. 2, pp. 5–7, 2015.
- [14] X. Xiao, "The analysis and improvement of potentiometer pressure transducer," in *Proceedings of the 13th National Conference on sensitive elements and sensors*, vol. 12356, pp. 318–320, Taiyuan, Shanxi, China, November 2020.
- [15] J. Ren, W. Zhang, Y. Wang et al., "A graphene rheostat for highly durable and stretchable strain sensor," *InfoMat*, vol. 1, no. 3, pp. 396–406, 2019.