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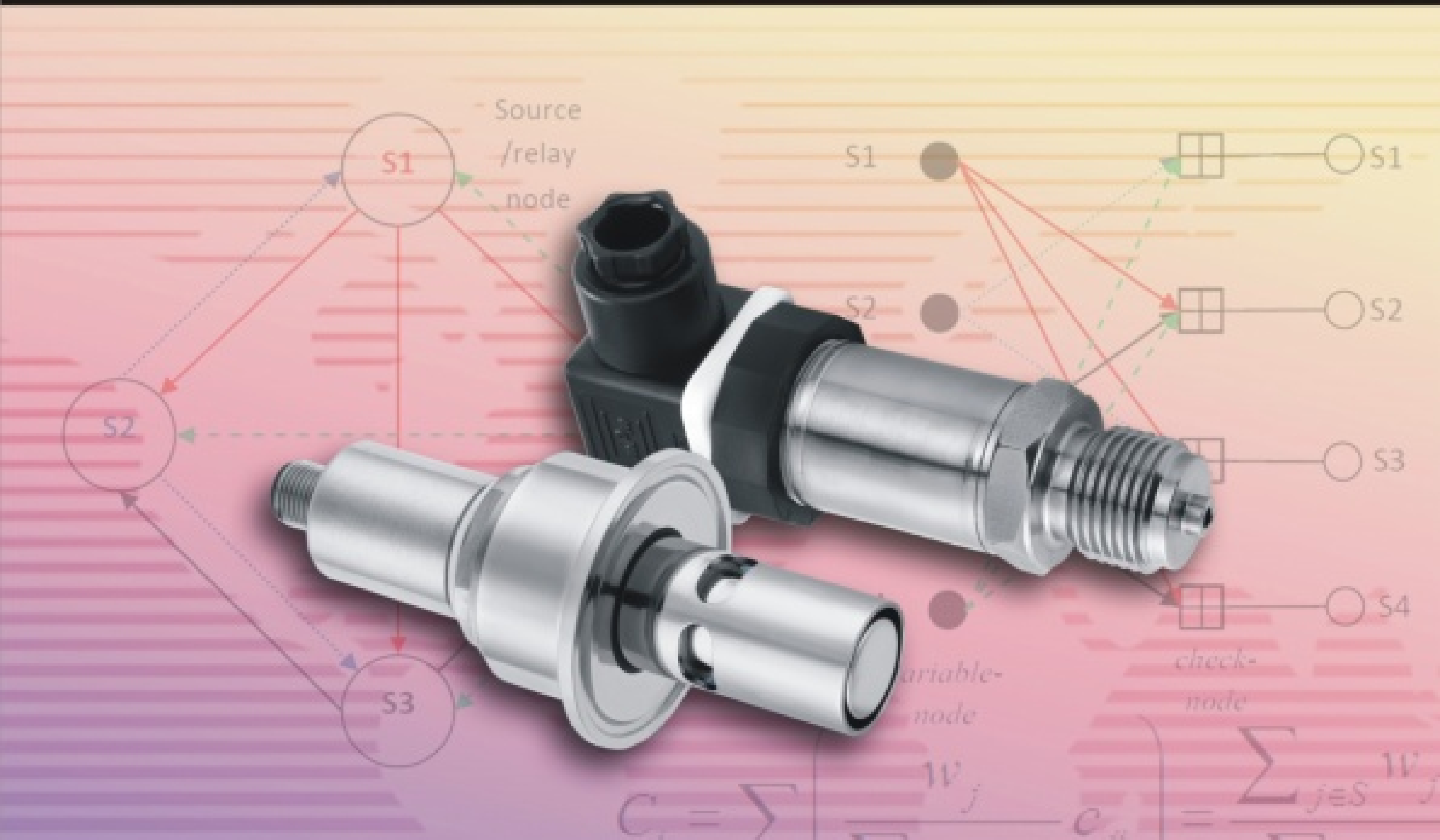

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Application of Partial Least Squares Regression to Static Magnetic Grid Displacement Sensor

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Abstract: In this paper, the author successfully proposed a new magnetic grid displacement data fitting model, based on partial least squares regression. Firstly, sinusoidal voltage is generated by the movement of magnetic sense hall on top of alnicos array. Then, handle the experimental data by the partial least squares fitting, obtained the relationship between values of Hall and displacement, and finally finish the displacement measure. The experiment results indicated that: This design can achieve displacement fitting goodness 99.98 % and maximum deviation of 0.1 mm. This method largely simplifies the production process of magnetic grid displacement sensor, reduces costs and achieves mass production. It has important implications in some special environment such as high temperature, low temperature, underwater and so on. *Copyright © 2013 IFSA.*

Keywords: Static magnetic grid, Sensor, Partial least squares regression (PLSR), Linear fitting.

1. Introduction

Traditional Linear displacement is measured by rotating transformer, photoelectric encoder, grating ruler, or magnetic railing ruler [1]. Rotating transformer, photoelectric encoder measure it through transform angular displacement into linear displacement. The mature grating ruler technology, with a high-precision, high-resolution ratio, singly following laser interference sensor, has shortcomings, either, like high construction cost, much complicated process, poor seismic performance and low shock resistance [2]. Given its high cost and small lifespan, grating ruler is usually difficult for volume-production and application.

Compared with grate ruler, magnetic railing ruler, a new prevalent linear displacement sensor, is higher structure simplification, more sensitive response, and easier miniaturization, above all, low cost and high stability [3]. Currently, the magnetic railing ruler is applied into some area with poor conditions, like machinery, petrochemical transportation, metallurgical, and water conservancy [4, 5]. However, the precision and resolution ratio need improving [6].

This paper firstly detected the original voltage signal by using permanent magnet as source and linear hall element as head. Then fitted equation was obtained through the regression of experimental data based on PLSR. Finally practical case is analyzed by the new method, and illustrates the improvement of precision, resolution ratio and stability [7].

2. The Basic Model of the Magnetic Grid

Magnet grid senor is displacement senor that utilizing the magnet interaction of magnet grid and head. It is a new type of digital senor with low cost, easy to install and use.

Magnet head use Hall senor as magneto sensor to generate signal. Because Hall senor has advantages, like firm structure, small size, light weight, long service life, easy to install, low power consumption, high frequency, vibration resistance, wide range of operating temperature and resistance to pollution or corrosion of dust, oil, moisture and salt spray.

This paper uses cheap permanent magnet as magnetic source. As shown in Fig. 1, permanent magnet are arranged in the matrix of the magnetic grid in accordance with the order of N-S-N-S (Traditional order is N-S-S-N-N). Permanent magnet produces a magnetic field that according to the fixed rule changes. The magnetic signal is converted into an electrical signal by Hall element. Then we can detect relative displacement of the object in real time according to the Hall element output.

2.1. Traditional Signal Processing Method

Traditional magnet grid senor uses signal processing method based on calibration-look-up table, that is, use high-precision grating ruler to calibrate magnetic railing ruler. During calibration, firstly handle the three-phase A/D voltage value by using some measures, like digital filter. Then, collect the grating ruler displacement output. Next, formulate a table about three-phase voltage values and corresponding grating ruler displacement values, and store it in SCM (Single Chip Micyoco) internal ROM. Finally, send the three-phase voltage signal into SCM for interval judgment look-up table, when magnet grid working, shown as Fig. 2.

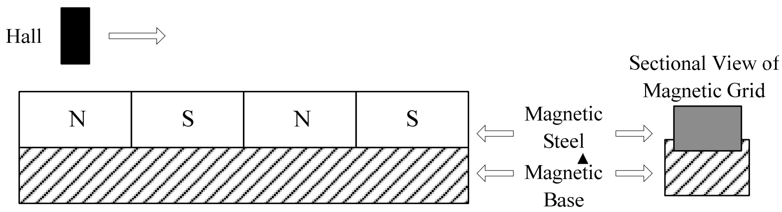

Fig. 1. Principle figure.

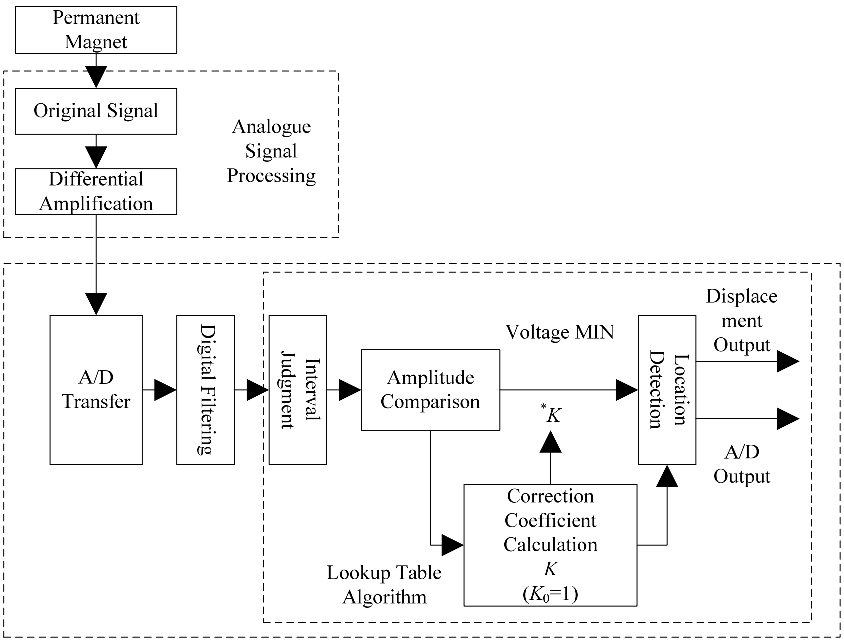

Fig. 2. Traditional Magnetic Grid Signal Processing.

2.2. The Principle of Magnetic Grid Signal Processing Based on PLSR

Given traditional signal-processing method high complexity and errors of table look up, the author do some improvement.

The magnetic grid sensor fit data by PLSR and then measure displacement. In data fitting, use machine tool for more accurate displacement measure. Establish the corresponding relationship between displacement and Hall voltage signal, combining with hall signal in the same time. Next, store the relationship in the single-chip. Fitting calculation and prediction results can be directly got through working.

The signal processing is shown in Fig. 3.

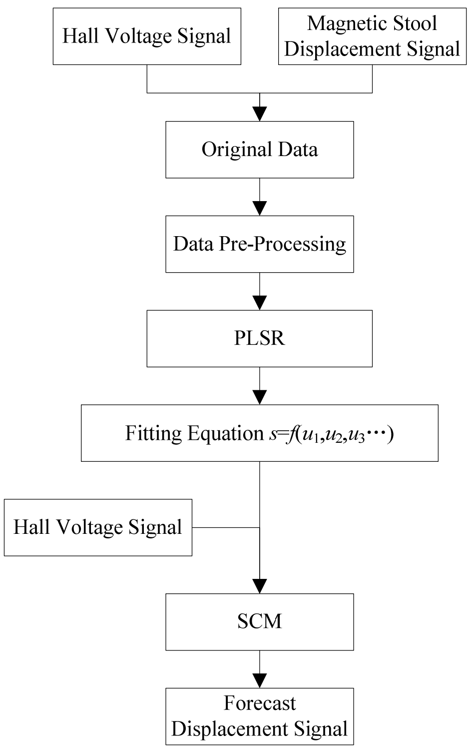

Fig. 3. Magnetic Grid Signal Processing.

Firstly, analysis and preprocess of the raw data. Fig. 4 is the relationship between hall and the displacement of the actual measured values.

Analysis found that the curve of each Hall has intermittent or cross and doesn't meet the ideal smooth. Therefore we should adjust for each endpoint and then cycle division. Last step is PLSR.

For the problem of missing data, we should polish with others Hall data. (Ideally, the data by different Hall collected are consistent and just the cycles are different) The processed data are shown in Table 1.

Considering the relationship of different Hall are affected by different alnicos, Adding interaction terms and quadratic terms to extend independent variables. And then analyze by PRLS.

3. Principles of Partial Least Squares Regression

Suppose that there were one dependent variable Y, k-explanatory variables ($X_1,X_2,\ldots,X_k$) and that the sample size was n, which constitute a data table $Y=[y]_{n\times1}$ and $X=[x_1,x_2,\ldots,x_k]_{n\times k}$. Firstly, extract the first principal component t_1 from the X, Which is the linear combination of x_1, $x_2,\ldots,x_k$. The first principal component t_1 should have the maximum degree of correlation with Y and should carry as much variability signals from X as possible. Then make the regression on t_1 for X and Y. If the regression equation has been satisfactory accuracy, the step stops; otherwise use the residual information to extract the second component t_2 and make the regression on t_1, t_2 for Y and X. Not until achieving a satisfactory accuracy would the repeated actions stop. If m-components are extracted from X, the PLSR will make the regression on $t_1,t_2,t_3,\ldots t_m$ for Y. $t_1,t_2,t_3,\ldots t_m$ are the linear combination of $x_1,x_2,\ldots,x_k$ ($m\leq k$), so the regression equation on the original variables X for Y can be expressed.

Steps of Partial Least Squares Regression:

1) Step one: Change the sample data into logarithm style. Change the log-linear data into linear data.

2) Step two: Exclude the sample-specific points. Standardize the logarithmic data. Then extract the first and second principle components (t_1, $t2$), and draw an elliptical figure on the t_1/t_2 plane, by which the sample-specific points are removed.

3) Step three: Extract the principle components from the selected variables by Partial Least Squares Regression. Make the regression process and get the regression equation in the context of a precise.

4) Step four: Transform the regression equation into antilogarithm style and get the log-linear relationship between the aircraft take-off performance and independent variables, which is, aircraft take-off performance prediction model.

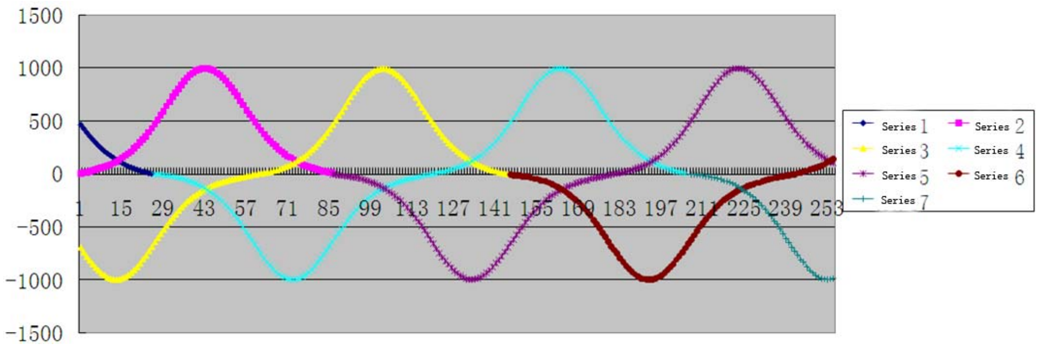

Fig. 4. Relationship between Hall and Displacement of the Actual Measured Values.

Table 1. Processed data.

y	x_1	x_2	x_3	y	x_1	x_2	x_3
0	122	133	-994	6	-151	995	-128
0.2	107	153	-983	6.2	-169	985	-111
0.4	91	172	-972	6.4	-187	976	-100
0.6	76	191	-955	6.6	-212	956	-89
0.8	66	210	-932	6.8	-236	937	-83
1	56	239	-905	7	-260	909	-72
1.2	45	263	-877	7.2	-290	880	-67
1.4	35	295	-843	7.4	-321	846	-55
1.6	25	325	-804	7.6	-351	813	-50
1.8	20	354	-770	7.8	-387	775	-44
2	10	392	-726	8	-424	736	-39
2.2	5	430	-687	8.2	-460	688	-33
2.4	-6	473	-642	8.4	-503	650	-27
2.6	-6	507	-603	8.6	-545	602	-16
2.8	-6	555	-564	8.8	-587	564	-16
3	-12	593	-525	9	-624	526	-5
3.2	-18	641	-486	9.2	-666	488	-5
3.4	-18	679	-446	9.4	-709	449	5
3.6	-24	727	-413	9.6	-757	411	5
3.8	-30	765	-379	9.8	-793	373	10
4	-36	803	-346	10	-830	339	15
4.2	-42	842	-312	10.2	-860	311	21
4.4	-48	875	-284	10.4	-896	282	31
4.6	-60	909	-256	10.6	-921	258	36
4.8	-72	937	-234	10.8	-945	229	47
5	-78	956	-212	11	-963	210	57
5.2	-90	975	-195	11.2	-981	186	68
5.4	-103	985	-175	11.4	-993	162	78
5.6	-121	995	-156	11.6	-993	153	94
5.8	-133	998	-139	11.8	-998	133	105

4. Experimental Analysis

For some equipment and accidental factors, some singular points may exist. Firstly, pick out them by using PLS. An elliptical figure analysis for the original data is as Fig. 5.

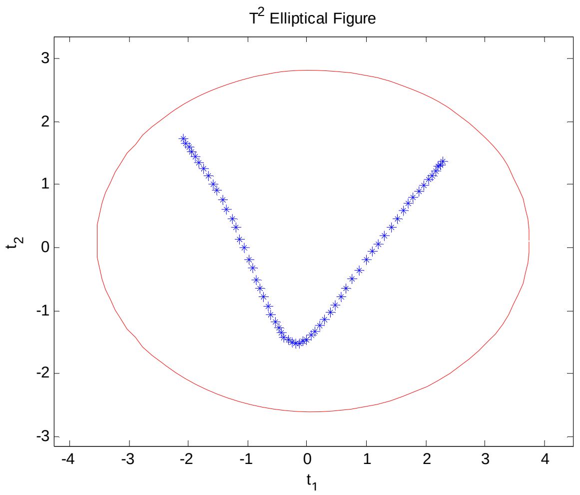

Fig. 5. T^2 Elliptical figure.

Some singular point really exists in the elliptical figure.

Fitting equation is got by analyzing the data, as shown in Table 1, using partial least squares regression.

$$y=0.00193287x_1-0.009886618x_2+0.020762786x_3+ +0.00000481x_1x_2+0.0000204x_1x_3+0.000000847x_2x_3- -0.00000183x_1^2+0.00000177x_2^2+0.00000698x_3^2+ +17.36227512$$

In these data, displacement fitting goodness of 99.98 %, maximum deviation of 0.1 and

Six points' deviation exceed 0.1 (Total 60 points, accounting for 10 %). The fitting goes well, specific results are as follows:

Table 2. Result Fitting.

No.	y	y_1	d	No.	y	y_1	d
1	0	0.038	0.038	31	6	5.964	0.036
2	0.2	0.217	0.017	32	6.2	6.233	0.033
3	0.4	0.417	0.017	33	6.4	6.388	0.012
4	0.6	0.647	0.047	34	6.6	6.582	0.018
5	0.8	0.842	0.042	35	6.8	6.689	0.111
6	1	0.977	0.023	36	7	6.943	0.057
7	1.2	1.184	0.016	37	7.2	7.077	0.123
8	1.4	1.360	0.040	38	7.4	7.350	0.050
9	1.6	1.610	0.010	39	7.6	7.521	0.079
10	1.8	1.762	0.038	40	7.8	7.717	0.083
11	2	2.013	0.013	41	8	7.909	0.091
12	2.2	2.168	0.032	42	8.2	8.212	0.012
13	2.4	2.425	0.025	43	8.4	8.383	0.017
14	2.6	2.611	0.011	44	8.6	8.716	0.116
15	2.8	2.707	0.093	45	8.8	8.845	0.045
16	3	2.952	0.048	46	9	9.112	0.112
17	3.2	3.134	0.066	47	9.2	9.259	0.059
18	3.4	3.407	0.007	48	9.4	9.492	0.092
19	3.6	3.542	0.058	49	9.6	9.618	0.018
20	3.8	3.785	0.015	50	9.8	9.864	0.064
21	4	4.024	0.024	51	10	10.059	0.059
22	4.2	4.284	0.084	52	10.2	10.233	0.033
23	4.4	4.502	0.102	53	10.4	10.390	0.010
24	4.6	4.711	0.111	54	10.6	10.542	0.058
25	4.8	4.861	0.061	55	10.8	10.784	0.016
26	5	5.085	0.085	56	11	10.930	0.071
27	5.2	5.208	0.008	57	11.2	11.144	0.056
28	5.4	5.437	0.037	58	11.4	11.402	0.002
29	5.6	5.622	0.022	59	11.6	11.558	0.042
30	5.8	5.839	0.039	60	11.8	11.820	0.020

The figures in Fig. 6 are fitting comparison chart and residual histogram, which respectively show comparison and deviation between the fitted values and the measured values. You can see clearly the precision of displacement prediction which obtained partial least squares regression in static magnetic grid displacement sensor.

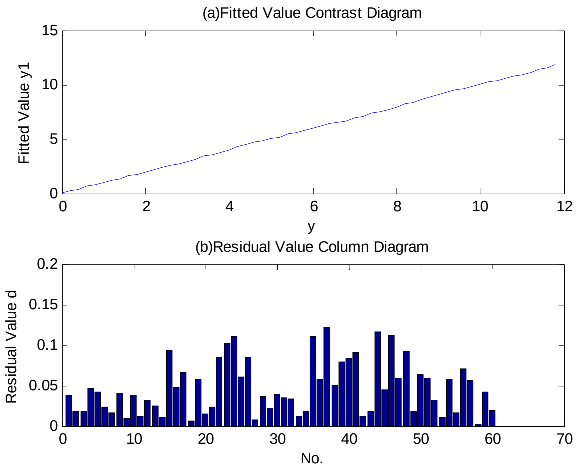

Fig. 6. Fitting Rendering

5. Conclusions

For these problems, including low resolution, complex process and high cost, this paper designed a new type of magnetic grid. The new design uses permanent magnet as magnetic grid source and linear Hall as the magnetic grid head, and obtains displacement in real time by moving of Hall produce electric signal changes with regularly. In the case of signal processing, we take advantage of partial least squares regression and calibrate with exact machine tool. When in the natural working condition, putting Hall voltage into the fitting equation will get the displacement output. In this design, the extremely simple circuit structure can reduce cost greatly. Experience indicated: this design achieves the displacement output that resolution of ±0.12 mm or less and is applicable to displacement detection of bad working circumstances.

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