Electronic Measurement Systems and Procedures for Optical Encoder and Force Sensor Studying

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Abstract* – The experimental measurement systems are very useful in engineering education because the students can use and verify their previous knowledge about sensors and transducers, signal conditioning and data processing. This paper presents two electronic measurement systems which enable the computerized study of the optical encoder and force sensor, respectively. The first sensor studying procedure performs the understanding and checking of the rotary incremental encoder working modes and methods for resolution improvement, displacement and velocity measurement, and motion sense discrimination. The second sensor studying procedure supposes the assignation of the measurement points, plotting the transfer characteristic and computing some parameters (zero error, differential sensitivity, relative sensitivity) of the strain gauge transducer; the measured mass of the tested object can also be displayed. Each electronic measurement system contains signal conditioning circuits, data acquisition board (organized around a microcontroller) and an IBM-PC compatible computer; the data acquisition board is serial connected to computer. A friendly user interface enables each computerized sensor study. The paper also includes many experimental results.

***Keywords:* sensor, measurement system, data acquisition board, computer.**

I. INTRODUCTION

Robotic sensors can be divided into two basic classes. The first, called *internal state sensors*, consists of devices used to measure position, velocity, or acceleration of robot joints and/or end effector. The following devices fall into this class: potentiometer, resolver, differential transformer, optical interrupter, optical encoder (absolute and incremental), tachometer, and accelerometer. The second class, called *external state sensors*, is used to monitor the geometric and/or dynamic relation between robot and its task, environment, or the object that is handling. Some important devices from this class are strain gauge sensor, pressure transducer, proximity sensor, ultrasonic sensor, tactile sensor, welding sensor [1].

The paper presents two electronic measurement systems designed for the study of one optical encoder (an internal state sensor) and one strain gauge sensor (an external state sensor).

A rotary incremental encoder (RIE) is used as optical encoder; this is an electro-mechanic device that converts the angular displacement of its shaft into three digital electric signals [2], denoted A, B and N, respectively; B is in quadrature with A. The optical encoder generates P_{Amax} pulses during a complete rotation of the encoder shaft. The angular displacement can be measured with different resolutions. The usual method for resolution improvement supposes adequate electronic circuits [3]. A soft method for angular displacement and rotational velocity measurement, resolution improvement and motion sense discrimination is presented in [3]; the resolution of the displacement measurement is four times improved in this way.

The strain gauge is one of the most important tools used to apply electrical measurement techniques to the measurement of mechanical quantities. Strain can be caused by forces, pressures, moments, heat, structural changes of the material and the like [4]. Because the strain-initiated resistance change of one strain gauge is extremely small, a Wheatstone full-bridge circuit is formed to convert the resistance change to a voltage change. If four strain gauges (SG_1, SG_2, SG_3, SG_4) are connected one to each of the bridge sides, and a positive (tensile) strain is applied to gauges SG_1 and SG_3, and the same but negative (compressive) strain to gauges SG_2 and SG_4 (as illustrated in Fig. 1), the total strain would be four times the strain on one gauge and the output voltage will be four times larger.

The electronic measurement system for optical encoder studying, presented in this paper, enables the understand of the sensor working modes and methods for resolution improvement, displacement and velocity measurement, motion sense discrimination.

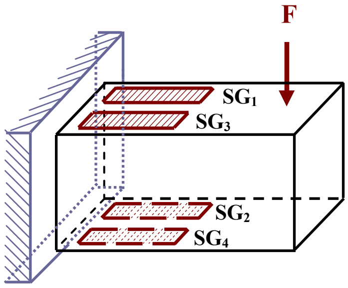

Fig. 1. Bending stress measurement with 4-gauge system.

The second electronic measurement system, presented in this paper, assures the computerized study of the strain gauge sensor using a friendly user interface. The studying procedure supposes the assignation of the measurement points, plotting the transfer characteristic and computing some parameters of the force transducer. The experimental equipment may be also used as weighing cell for some objects.

Both experimental systems are very useful in higher education and research activities because they illustrate how the same sensor can measure different physical variables, and they enable the application of different students' knowledge about sensors, microcontrollers, computers.

II. ELECTRONIC MEASUREMENT SYSTEM FOR OPTICAL ENCODER STUDYING

A. Hardware Architecture and Measurement Method

The electronic measurement system with optical encoder (Fig. 2) performs the motion sense discrimination, angular displacement and rotational velocity measurement based on the output signals A and B of the rotary incremental encoder. Fig. 3 illustrates the hardware architecture of this experimental system; ϕ is the measured displacement, and the signals denoted P and N command the positive and negative, respectively motion sense.

The main components of the electronic measurement system are the following:

- IBM-PC compatible computer,
- data acquisition board,
- TTL/RS-232 converter,
- rotary incremental encoder (RIE),
- driving module,
- motor.

The encoder under test is of SUMTAK origin, the LBL-007-1000 type; it is characterized by P_{Amax}=1000 and $\Delta\phi = 0.36\,\mathrm{deg}$ is its displacement resolution.

Fig. 2. Electronic measurement system for optical encoder studying.

The data acquisition board (based on the central unit presented in [5]) commands the motor driving circuit, and this motor moves the encoder shift. The data acquisition board is organized around a microcontroller from the 80C552 family (Philips Semiconductors [6]), which is very flexible and versatile, with excellent control possibilities in various industrial applications [7,8]. Hardware resources of the interface enable the engendering of some digital or analogue commands (for the motion control or sensor supply) and the acquisition of many digital or analogue signals necessary for computing some motion variables or technological parameters [9]. The data acquisition board is endowed with adequate software resources for connecting the rotary incremental encoder, for improvement its resolution, for computing motion variables. Between the interface and computer there is a soft interaction. The intelligent interface is serial connected to IBM-PC compatible computer that assures the final data processing, displays the measured variables and computed parameters, assures a simple dialogue with the user.

Program modules (to the intelligent interface level and computer level) enable the study of encoder. The program modules at the data acquisition level are written in the assembly language and C for 80C552 microcontroller [3]; each program module implements an elementary function (serial dialogue with computer, control of the mechanical subsystem, acquisition of the analogue and digital signals etc.).

The measurement method (in detail presented in [3]) is based on the output signals A and B of the rotary incremental encoder. The logic levels of signals A and B are always correlated before and after a new front of pulses A or B, for each motion sense.

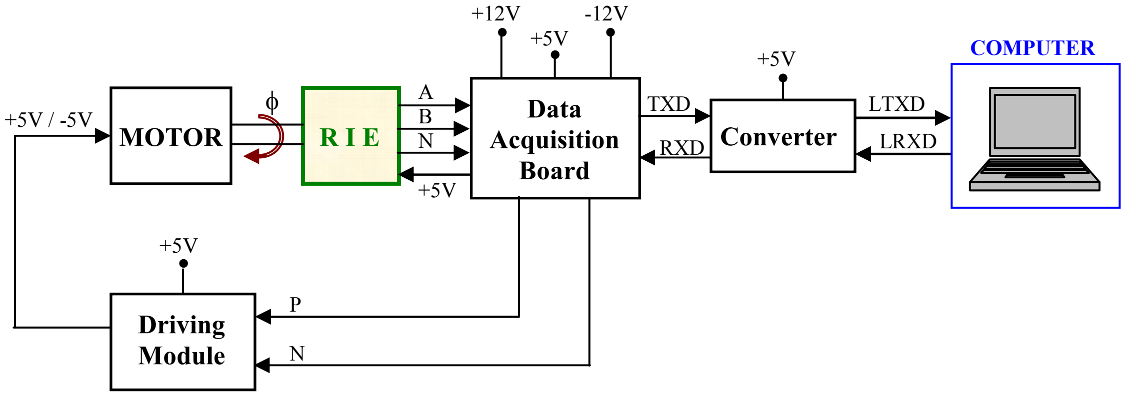

Fig. 3. Hardware architecture of the electronic measurement system for optical encoder studying.

The microcontroller master program (in assembly language) reads the digital inputs A and B, after each 115μs. The acquisition routine compares the last (Q_{A1}, Q_{B1}) with the last but one (Q_{A0}, Q_{B0}) logic levels of the signals A and B, to detect the motion sense and compute the angular displacement. Each new front of pulses A and B must be detected. The displacement-counter always counts up the last detected front of A or B, and the resulted number is multiplied with $\frac{\Delta\phi}{4}$ to obtain the angular displacement of the shaft. In this way, the experimental system measures the displacement with a resolution divided-by-four, and the motion sense is detected too.

During a complete rotation of the shift encoder, 4000 fronts (of signals A or B) are detected and counted; so, each new front corresponds to $\frac{1}{4000}$ rotations. N_S fronts are detected in the period $\Delta T_S = 1s$, if the shaft encoder moves in the same sense during this period. The number N_S corresponds to the mean rotational velocity of the shaft (denoted n), in revolutions per minute:

$$n[\text{r.p.m.}] = N_S \frac{60}{4 \cdot P_{A\max}} = N_S \cdot n_o[\text{r.p.m.}] , \qquad (1)$$

where n_o is the rotational velocity increment. So, the resolution of the rotational velocity measurement is n_o. For the encoder under test, P_{Amax}=1000 and n_o=0,015 r.p.m.

B. Sensor Studying Procedure

The procedure for studying the rotary incremental encoder enables the displacement measurement (with 0.09deg. resolution), mean rotational velocity measurement (with 0.015 r.p.m. resolution), and motion sense discrimination. The main steps of this procedure are presented below.

Two fields appear in the dialog window from Fig. 4: *Motor* and *Measurements*. A vector, on its initial position on a circle, is also represented. The measurement process starts when the motion sense (positive or negative) of the motor shaft is selected and the *Start* button is then activated (Fig. 4). During the measurement process, the mean value of the rotational velocity (in r.p.m.), angular displacement (in deg.) and displacement sense (positive or negative) are displayed (Fig. 4 and Fig. 5). The vector position reflects the measured angular displacement; this vector moves in counterclock-wise when the motion sense is positive.

If the *Stop* button is activated, the motion stops, the last measured displacement is memorized, the rotational velocity becomes zero, the vector rests in its last position and the motion sense is not displayed. The next motion sense of its shaft can be changed only if the motor is stopped. The displacement and rotational velocity become zero when the *Start* button is activated again. To return in the main program, the motor must be stopped and the *Exit* button should be activated.

The electronic measurement system with optical encoder is very useful in higher education and research activities because it illustrates how the same device can measure different physical variables, a soft method for resolution improvement and sense discrimination can be studied and verified, and the hard and soft previous students' knowledge about microcontroller can be applied.

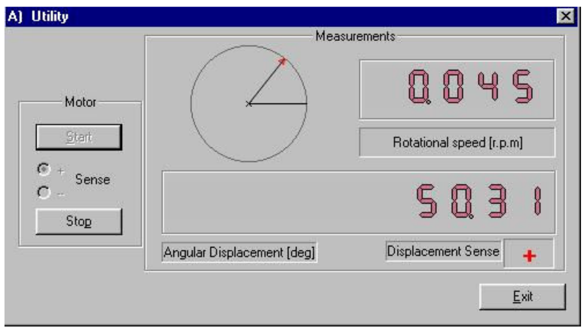

Fig. 4. Measurements for positive motion sense.

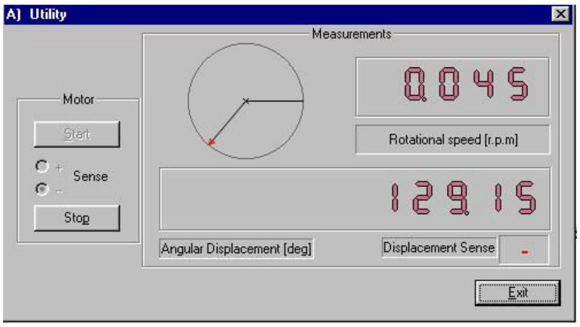

Fig. 5. Measurements for negative motion sense.

III. ELECTRONIC MEASUREMENT SYSTEM FOR FORCE SENSOR STUDYING

A. Hardware Architecture and Measurement Method

The picture of the experimental system that enables the study of one force sensor based on strain gauges is shown in Fig. 6. The hardware architecture (illustrated in Fig. 7) consists of strain gauge sensor, signal conditioning module, data acquisition board, TTL/RS-232 converter, power supply for these components, and an IBM-PC compatible computer; F is the measured force.

Four identical strain gauges (SG_1, SG_2, SG_3, SG_4) are connected one to each of the Wheatstone bridge sides: SG_1 and SG_3 on the top surface, and SG_2 and SG_4 on the bottom surface of the elastic element, as we can see in Fig. 1. The bridge excitation is the continuous voltage V_S, and the output voltage is

$$V_{IN} = GF \cdot \frac{V_S}{4} \cdot (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4) = GF \cdot V_S \cdot \varepsilon, \qquad (2)$$

where ε_i is the strain applied to the gauge SG_i, and GF is the gauge factor [4,10].

Fig. 6. Electronic measurement system for force sensor studying.

The signal conditioning module contains many electronic circuits:

- One instrumentation amplifier (INA 114),
- A noise suppression circuit and amplifier (designed with operational amplifiers),
- One voltage reference and three regulators that prepare the reference voltage for INA114, the excitation of the strain gauge sensor and the supply voltages of the instrumentation amplifier.

The data acquisition board is based on the same central unit presented in [5]. The hardware resources of this interface enable the acquisition of analogue voltage U_O for computing some variables or parameters.

B. Sensor Studying Procedure

The procedure for studying the force sensor supposes three stages:

- Assignation of the measurement points;
- Plotting the transfer characteristic and computing some parameters of the force transducer;
- Application.

1) Assignation of the measurement points

The dialog window for the assignation of the measurement points is shown in Fig. 8.

- First time, the student must specify the number of measurement points (minimum 2 and maximum 10).
- Without any object on the sensor table, the user presses the "Start measurements" button. After the validation of the first measurement point by pressing the "Point validation" button, the characteristic gravitation force of the tested object and output voltage of the signal conditioning module are displayed for this point, in the fields G[N] and U_O[V], respectively.
- The student must put then the first object on the sensor table and introduce its mass (m[g]). After the validation of the second measurement point by pressing the "Point validation" button, the characteristic values are displayed for the second point, in the fields G[N] and U_O[V].
- Continue the point assignation until the last point is validated. The mass for the current measurement point must be always larger then the mass for the previous point.
- "Graphic displaying" button must be press for advance to the next stage of the studying procedure.

2) Plotting the transfer characteristic and computing some parameters of the force transducer

Fig. 9 illustrates the dialog window for this stage. The measurement points 1,2,3,… (assigned in the previous stage of this procedure) are depicted in the plane (G,U_O).

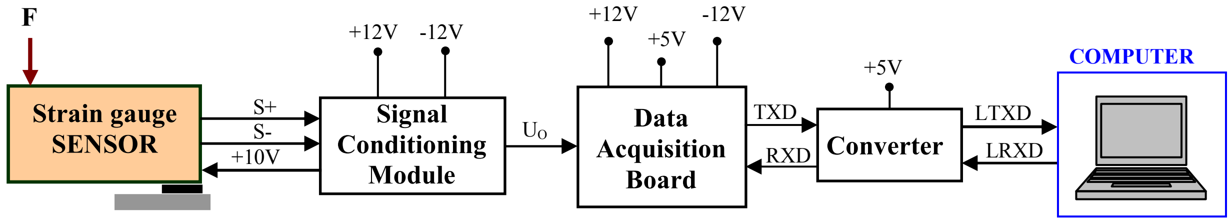

Fig. 7. Hardware architecture of the electronic measurement system for force sensor studying.

In the right side of the dialog window from Fig. 9 there are two fields ("Processing" and "Results") and many buttons for computing some characteristic parameters of the transducer. This second stage also supposes many steps.

- The zero error is computed and displayed in the "Results" field if the student presses the "Zero error" button (Fig. 9).
- The student can see the linearized transfer characteristic U_O=f(G) when the "Linearization" button is activated (Fig. 9).
- The transfer characteristic with the zero error compensated can be seen in the dialog window if the "Zero error compensation" button is pressed (Fig. 9).
- The differential sensitivity can be computed for each line segment of the transfer characteristic U_O=f(G) using the "Differential sensitivity" button (Fig. 9). The differential sensitivity formula and the minimum, maximum and ideal values of this parameter are all displayed in the "Results" field (Fig. 9).

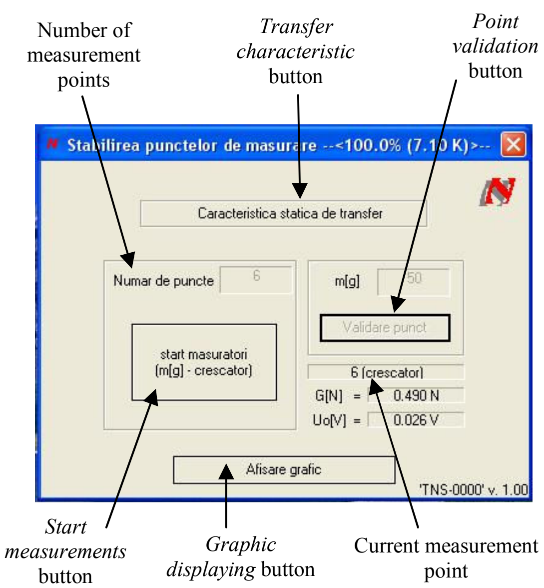

Fig. 8. Dialog window for the measurement point assignation.

- The relative sensitivity can be also computed for each line segment of the transfer characteristic U_O=f(G) using the "Relative sensitivity" button (Fig. 9). The relative sensitivity formula and the minimum, maximum and ideal values of this parameter are all displayed in the "Results" field of the dialog window.

3) *Application*

A small table fixed on the strain gauge sensor enables the weighing of different objects put on this table (Fig. 6). When the user presses the "Experimental measurements" button (Fig. 9), the experimental measurement system becomes an electronic weighing cell. The computer monitor displays the mass of the tested object (Fig. 10).

IV. CONCLUSIONS

The paper presents two electronic measurement systems very useful in higher education. These experimental systems enable the computerized study of the rotary incremental encoder and strain gauge sensor. Each measurement system contains a data acquisition board configured around a microcontroller from the 80C552 family; it is endowed with adequate software resources for connecting the sensor and computing different variables or transducer parameters. The data acquisition board is serial connected to IBM-PC compatible computer. The computer performs the final data processing, displays the measured variables, computed parameters or transfer characteristics, and assures an easy dialogue with the user.

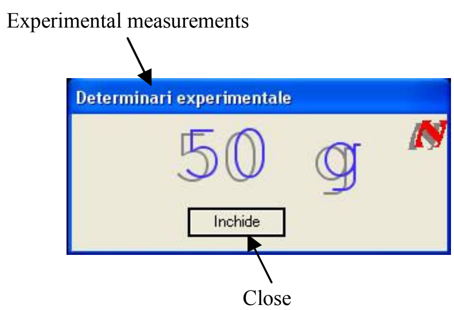

Fig. 10. Dialog window for weighing.

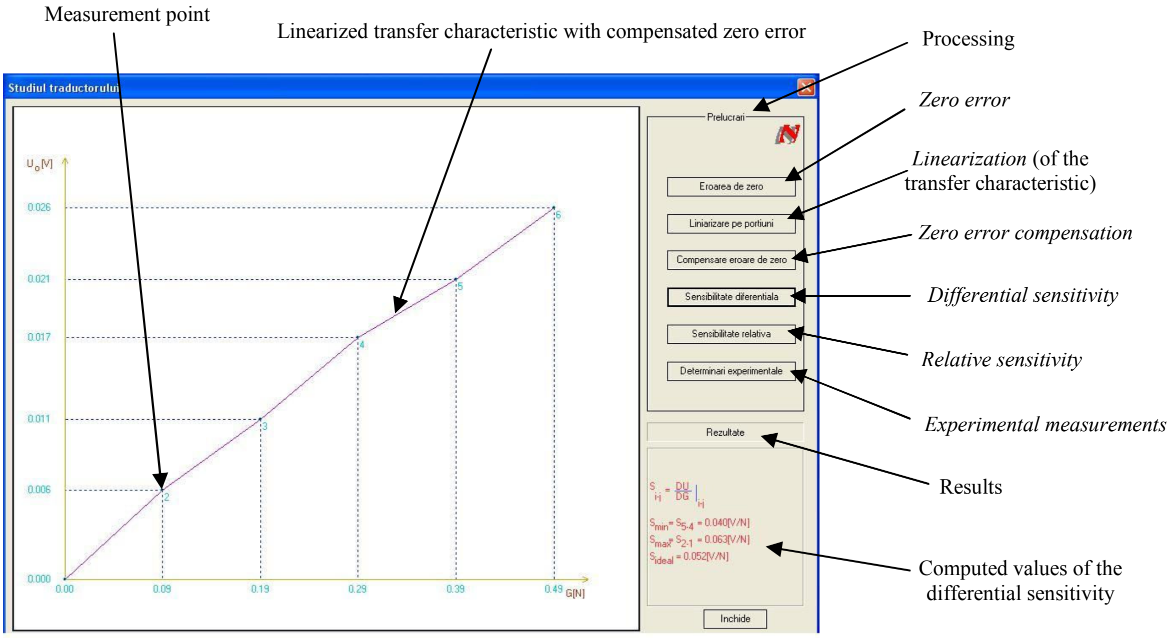

Fig. 9. Linearized transfer characteristic with compensated zero error and computed values of relative sensitivity.

The students can learn to use microcontrollers in such applications even if 80C552 is not very fast (because it is older generation). Each data acquisition board may be then easy configured around a new microcontroller, more efficient in applications.

Many experimental results obtained using the sensor studying procedures are also presented in this paper. Other sensors can be then studied using alike electronic measurement systems and procedures.

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