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Calibration of force sensor

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Keywords: force sensor, measurement, measurement error, measurement uncertainty, calibration.
Abstract: The paper deals with the issue of calibration of an analogue force sensor with a voltage output. For measurement, the force sensor uses a deformation member with a tensometric bridge and a measuring amplifier. This measuring chain must be used for force measurement, but the measurement uncertainty of this measuring chain is not known. Force sensors are planned for use in intelligent traumatological external fixation systems.

1 Introduction

Force sensors are always based on the measurement of external force effects such as deformations, dynamic effects or pressure changes of the pressure measuring medium. It is therefore always an indirect measurement, which means that the sought information about the force must be determined indirectly by calculation from experimental measurements [1-5]. This process brings with it a number of factors related to the implementation and evaluation of the process of measuring and identifying force action. From the point of view of feasibility, it is possible to create a deformation body with your own hands [6-10]. This study deals with a force sensor with an "S" shaped deformation member, where the deformation is determined using a strain gauge measuring bridge (Figure 1).

Figure 1 Force sensor

The measuring chain (Figure 2) contains a filter and a measuring amplifier of the output signal from the tensometric measuring bridge of the force sensor. An important part is also the reference power supply of the tensometric measuring bridge, which can also significantly affect the force measurement errors. The output signal of the measuring chain is an analogue signal in the form of electric voltage or electric current. Alternatively, the signal can also be in the form of a digital signal. For the mechanical attachment of the force sensor, hanging screws are applied, which are intended for measuring the tensile force. If it is necessary to measure the compression force, it is recommended to use silent blocks, which can partially dampen sudden dynamic changes in force action [11-16].

Force sensors are planned for use in intelligent traumatological external fixation systems, where the force exerted by this device will be measured. For this purpose, it is necessary to carry out verification and calibration of selected force sensors.

Figure 2 Measurement chain with force sensor

2 Transformation and calibration characteristics

Verification and calibration of the force sensor was carried out by two methods. The first method was a direct method, using reference weights that were directly applied to the force sensor for tensile stress and compressive stress. For forces that were outside the range of the applied weights, an indirect method was used in which the weights were applied to the force sensor using a lever mechanism that increased the magnitude of the force applied to the force sensor.

The output value of the force sensor was the analogue electrical voltage at the output of the measuring bridge for this force sensor.

The transformation characteristics were evaluated from the measured values, where the sensor output voltage values were displayed depending on the force acting on the force sensor. Calibration characteristics were then processed from these measurements, where the dependence of the applied force on the value of the sensor output voltage was evaluated. These dependencies were approximated by a linear model, which can then be used to convert the measured values of the sensor output voltage to the values of the applied force.

Figures 3 to 10 show the processed transformation and calibration characteristics of the verified force sensor for both tensile and compressive stress. A mathematical model of the approximate dependence is also presented for the calibration characteristics.

The regression coefficients have a value very close to zero and this means that the linear approximation is a suitable mathematical model for the mathematical description of these experimental dependencies.

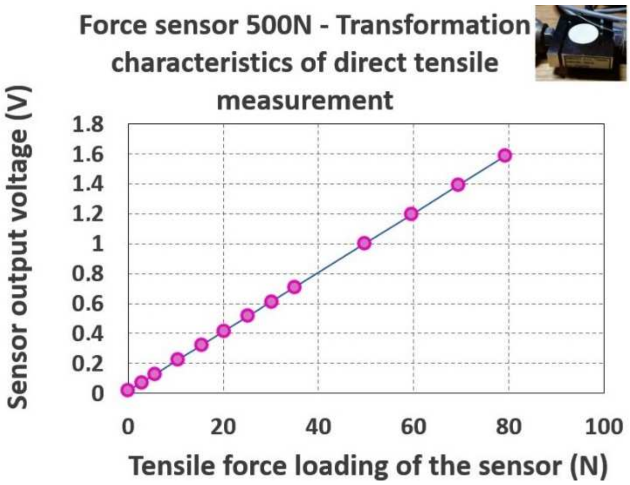

Figure 3 The transformation characteristic of direct tensile measurement using the force sensor with range 500N

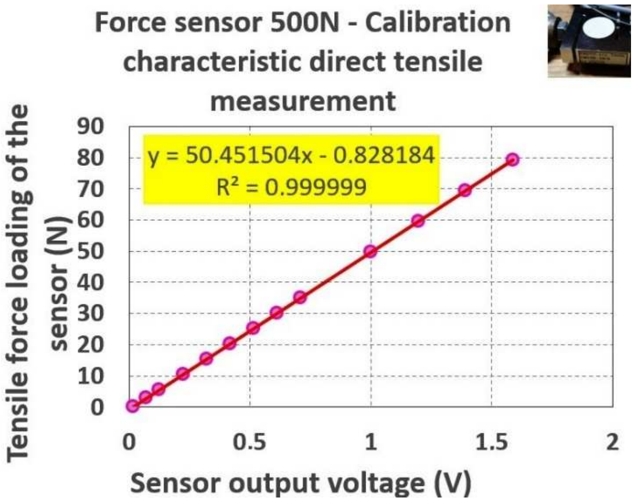

Figure 4 The calibration characteristic of direct tensile measurement using the force sensor with range 500N

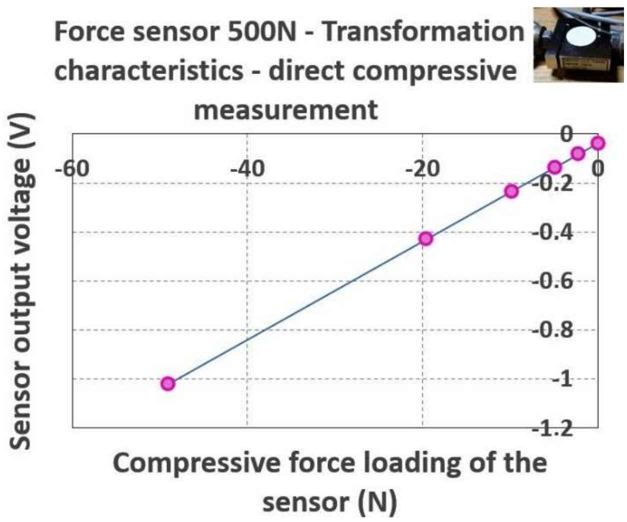

Figure 5 The transformation characteristic of direct compressive measurement using the force sensor with range 500N

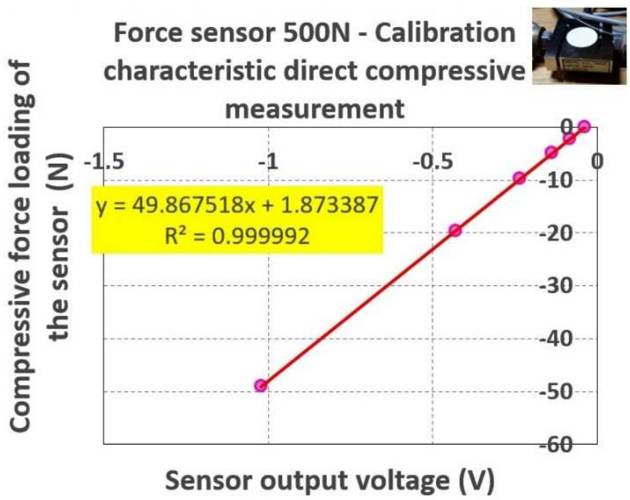

Figure 6 The calibration characteristic of direct compressive measurement using the force sensor with range 500N

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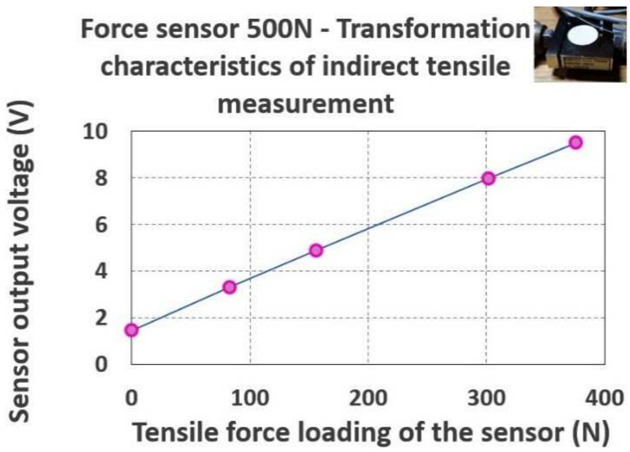

Figure 7 The transformation characteristic of indirect tensile measurement using the force sensor with range 500N

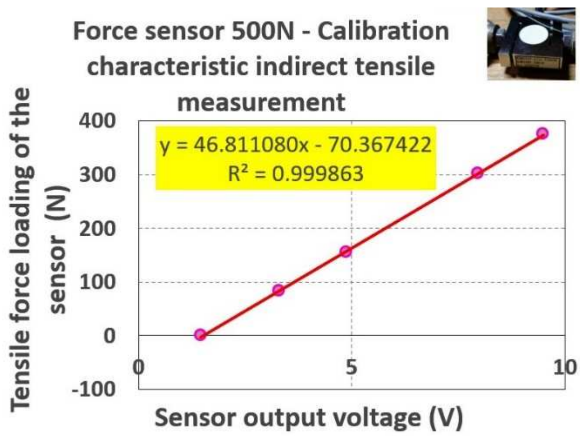

Figure 8 The calibration characteristic of indirect tensile measurement using the force sensor with range 500N

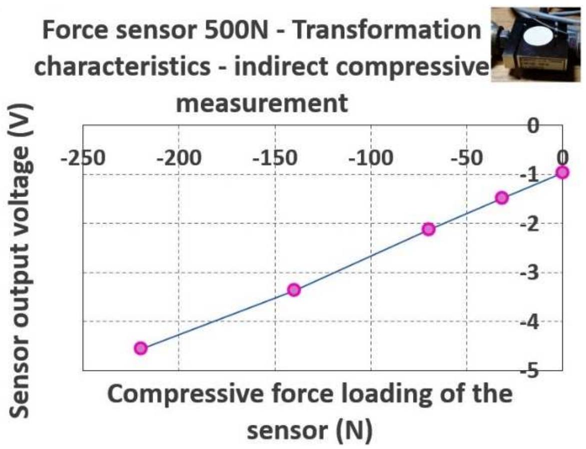

Figure 9 The transformation characteristic of indirect compressive measurement using the force sensor with range 500N

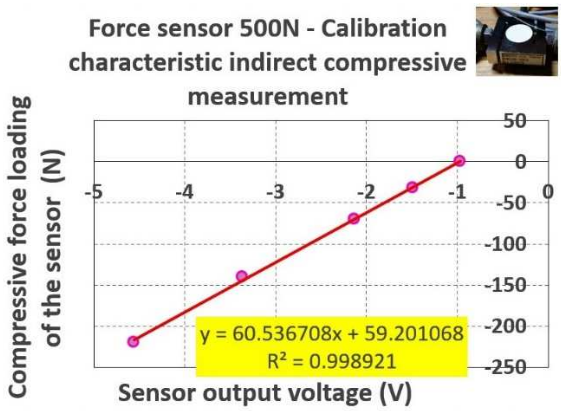

Figure 10 The calibration characteristic of indirect compressive measurement using the force sensor with range 500N

Each point shown on these characteristics is the result of a set of measurements under the same conditions, where the minimum number of replicate measurements was ten. An estimate of the mean value of the measured quantity was then determined from these measurements.

3 Measurement uncertainty

The process of verification and calibration of the sensor also includes the evaluation of measurement uncertainty. Measurement uncertainties describe the extent to which the obtained data can be trusted, and at the same time it is possible to determine the level of random errors, which we consider as a component of measurement uncertainty. In the direct measurement, standard deviations of a series of measurements were used. For indirect measurements, standards for determining measurement uncertainty (EAL-R2, GUM, VIM3) were used, and from these values, the combined measurement uncertainties for the calibrated force sensor were determined (Figures 11-14).

The standard deviation (1) of a series of measurements was determined from the measured data:

$$S_D = \sqrt{\frac{\sum_{i=1}^{n}\left(\overline{F}_M - F_{Mi}\right)^2}{n-1}}. \qquad (1)$$

Where n is number of measurements, F_M is estimate of the mean value of the force determined by the force sensor and F_{Mi} is measured value of force sensor.

Then, from this standard deviation, the standard uncertainties determined by Method A were determined (2):

$$u_A = \frac{S_D}{\sqrt{n}}. \qquad (2)$$

The standard uncertainty determined by method B was obtained from the relation (3):

$$u_B = \frac{MPE}{k}. \qquad (3)$$

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Where *MPE* is maximum permissible error of measured value and *k* is coverage factor.

Then the combined uncertainty was determined from the standard uncertainties determined by method A and method B (4):

$$u_C = \sqrt{\left(u_A^2 + u_B^2\right)}. \tag{4}$$

This relationship for determining the combined measurement uncertainty can be used for direct measurement. For indirect measurement, it is necessary to analyse the measurement model and determine the measurement uncertainty for the measured force values, including the covariance.

The mathematical model of the measurement is defined from the calibration characteristic, where the approximation was realized by a linear model.

However, even the values of the standard deviations already have a certain informative value, because they determine the degree of dispersion of the measured values around the estimate of the mean value. From Figures 11 to 14, it can be seen that the values of the standard deviations are very small compared to the nominal values, so it can be concluded that the force sensor is usable for practical use.

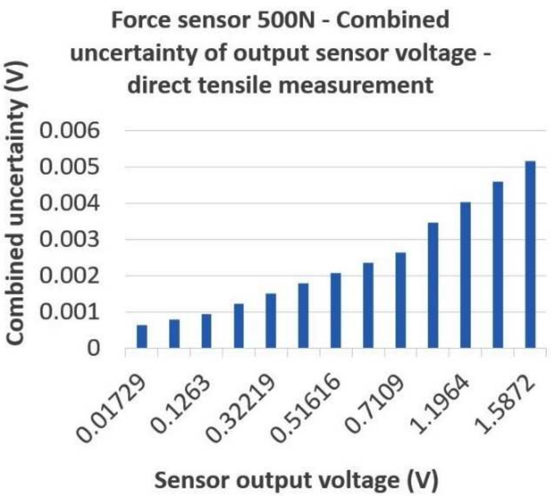

Figure 11 The combined uncertainty of output sensor voltage for direct tensile measurement

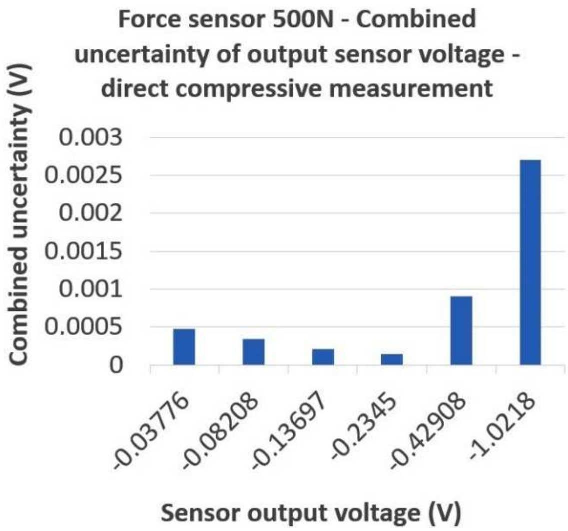

Figure 12 The combined uncertainty of output sensor voltage for direct compressive measurement

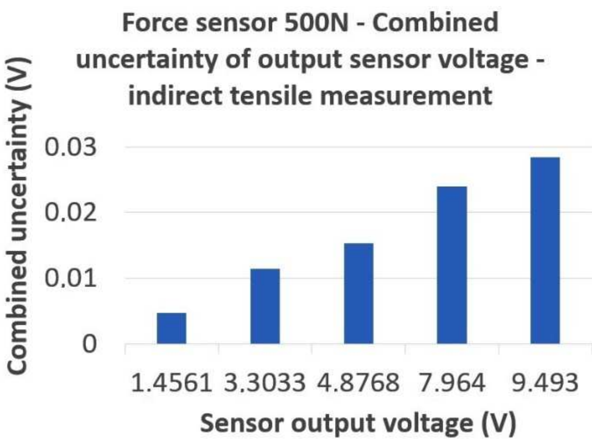

Figure 13 The combined uncertainty of output sensor voltage for indirect tensile measurement

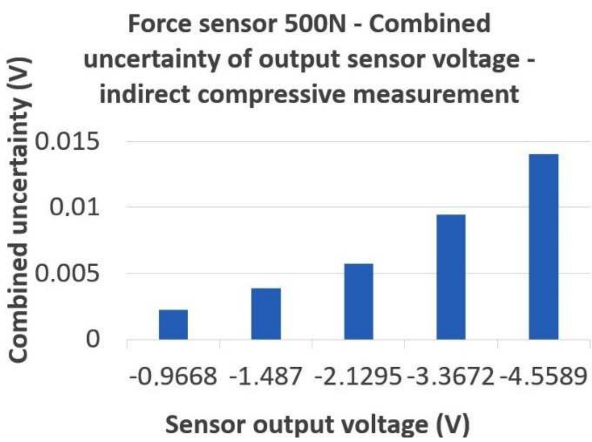

Figure 14 The combined uncertainty of output sensor voltage for indirect compressive measurement

4 Conclusion

The process of verifying the functionality of the force sensor and its calibration provide a mathematical

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measurement model that is the first starting point for assessing the state of the force sensor. In any similar case, it is also necessary to analyse the uncertainty of the measurement in order to determine how it is possible to trust the measured values.

In further future research, measurement uncertainties will also be analysed for indirect measurement, where the situation is more complex than for direct measurement.

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References

[1] DECREE 161/2019 of the Office for Standardization, Metrology and Testing of the Slovak Republic of 27 May 2014 on measuring instruments and metrological control, 2019.

[2] Directive 2009/34/EC of The European Parliament and of the Council of 23 April 2009 relating to common provisions for both measuring instruments and methods of metrological control, 2009.

[3] EA-4/02 1999 Expression of the Uncertainty of Measurement in Calibration. European co-operation Accreditation Publication Reference. December 1999, 1999.

[4] JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3). First edition September 2008, [Online], Available: http://www.iso.org/sites/JCGM/GUM-JCGM100.htm [05 Apr 2023], 2008.

[5] JCGM 104 - Evaluation of measurement data – An introduction to the "Guide to the expression of uncertainty in measurement" (ISO/IEC Guide 98-1). First edition July 2009, [Online], Available: http://www.bipm.org/en/publications/guides/gum_print.html [05 Apr 2023], 2009.

[6] KELEMENOVÁ, T., DOVICA, M., KOLARIKOVA, I., BENEDIK, O., MAXIM, V.: Verification of Force Transducer for Direct and Indirect Measurements, *MM Science Journal*, Vol. 2021, No. October, pp. 4736-4742, 2021. https://doi.org/10.17973/MMSJ.2021_10_2021021

[7] KELEMENOVÁ, T., KELEMEN, M., VIRGALA, I., MIKOVA, L., PRADA, E., VARGA, M., SEMJON, J., SUKOP, M., JANOS, R., TULEJA, P., MARCINKO, P.: Verification of the Torque Gauges, *MM Science Journal*, Vol. 2022, No. March, pp. 5533-5538, 2022. https://doi.org/10.17973/MMSJ.2022_03_2022014

[8] BOŽEK, P.: Robot path optimization for spot welding applications in automotive industry, *Tehnicki vjesnik / Technical Gazette*, Vol. 20, No. 5, pp. 913-917, 2013.

[9] DUCHOŇ, F., BABINEC, A., KAJAN, M., BEŇO, P., FLOREK, M., FICO, T., JURIŠICA, L.: Path planning with modified A star algorithm for a mobile robot, *Procedia Engineering*, Vol. 96, pp. 59-69, 2014.

[10] PÁSZTÓ, P., HUBINSKÝ, P.: Mobile robot navigation based on circle recognition, *Journal of Electrical Engineering*, Vol. 64, No. 2, pp. 84-91, 2013.

[11] ABRAMOV, I.V., NIKITIN, Y.R., ABRAMOV, A.I., SOSNOVICH, E.V., BOŽEK, P.: Control and Diagnostic Model of Brushless DC Motor, *Journal of Electrical Engineering*, Vol. 65, No. 5, pp. 277-282, 2014.

[12] KONIAR, D., HARGAŠ, L., ŠTOFAN, S.: Segmentation of Motion Regions for Biomechanical Systems, *Procedia Engineering*, Vol. 48, pp. 304-311, 2012.

[13] VARGA, M., VAGAŠ, M.: Experimental Vision System Setup Based on the Serial Configuration Interface, *Acta Mechatronica*, Vol. 6, No. 3, pp. 41-44, 2021. https://doi.org/10.22306/am.v6i3.77

[14] MALAGA, M., BROUM, T., SIMON, M., FRONEK, M.: Industrial robotics as an important part of modern production automation, *Acta Mechatronica*, Vol. 7, No. 4, pp. 31-36, 2022. https://doi.org/10.22306/am.v7i4.91

[15] ROMANCIK, J., VAGAS, M., GALAJDOVA, A.: Pick & Place automated workplace based on CC-Link IE Field basic communication, *Acta Mechatronica*, Vol. 7, No. 1, pp. 9-12, 2022. https://doi.org/10.22306/am.v7i1.84

[16] KURYŁO, P., PIVARČIOVÁ, E., CYGANIUK, J., FRANKOVSKÝ, P.: Machine vision system measuring the trajectory of upper limb motion applying the Matlab software, *Measurement Science Review*, Vol. 19, No. 1, pp. 1-8, 2019.

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