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AN EXPERIMENTAL APPROACH TO CALIBRATE A FORCE-TORQUE SENSOR USING A NEURAL NETWORK

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PRESENTATION

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AN EXPERIMENTAL APPROACH TO CALIBRATE A FORCE-TORQUE SENSOR USING A NEURAL NETWORK

Abstract. *The force and torque sensor is a tool widely used in industrial processes and research centers where data need to be obtained with high accuracy. This paper aims to calibrate a ATI, Industrial Automation, Gamma model 3805 force and torque sensor, using neural networks. To perform the calibration, a experimental setup was assembled. The experimental setup envolved the force and torque sensor, a National Instruments myDAQ © data acquisition board and a pulley set system for the distribution of weights between the axes of the sensor. The data acaquired was used to feed the Neural Network system and the Labview software was used to. To model Neural Network, was used a specific Matlab software toolbox. The experiment was conducted by placing loads with different values in known positions, so that the forces and torques along the three axes, were known. After this procedure, raw data voltage was collected. These measures was used to feed the neural network developed in a Matlab toolbox. The partial results obtained were satisfactory and the neural network, tested with experimental data presented minimum values of mean and degree of accuracy close to one. The work is in progress and the next step is to conduct a new experiment using the measurements of the calibrated force and torque sensor in the control loop of a robotic manipulator to control the robot force on a body.*

Keywords: *force and torque sensor, neural network, experimental, data acquisition.*

1. INTRODUCTION

In the last decades, many research have been done, regarding to force and torque sensors. In the literature, we can highlight some works like (Lin *et al.*1997), where the authors presents an on-line calibration methodology for robot relative positioning inaccuracy. According to the authors, this methodology eliminates the need for time-consuming off-line calibrations relying on accurate models and complicated procedures. To implement this methodology, a vision system, a 3D force/torque sensor, and control strategies involving Neural Networks (NNs) were incorporated with an industrial robot.

In (Cao *et al.* 2009), the authors, aiming at resolving the disadvantages such as low decoupling precision of the traditional method, used a linear decoupling method, based on neural network. The paper analyzes the reasons why coupling exists in the multi-axis force sensor, and then according to this phenomenon, the method gains a weight matrix by using the associational function of the linear model of the neural networks and the matrix can reflect the coupling force of different dimensions correctly. Comparing to the traditional static decoupling method, with the method state by the authors, it improves the precision of decoupling greatly. At the end of the paper, experiments and traditional decoupling method are shown to compare and prove the effectiveness of the used method.

In (Liang *et al.* 2010) the authors present a novel device for measuring components of forces and moments along and about three orthogonal axes based on E-type membranes compared to conventional sensor based on cross beams. After design and analysis of both types of sensors, they chose to fabricate a six-dimensional wrist force/torque sensor based on E-type membranes. Also, the calibration and decoupling based on Neural Network method were performed, and the sensor possesses excellent characteristics such as high measurement sensitivity, overload protection, good linearity, and weak couplings between components. In authors opinion, its maximum interference error and nonlinearity error are 1.6% F.S. and 0.17% F.S., respectively.

In (Liang et al., 2011), the authors describe the design of a micro-scale manipulator based on a six-DOF compliant parallel mechanism (CPM), which is featured by piezo-driven actuators and integrated force sensor capable of delivering six-DOF motions with high precision and providing real-time force information for feedback control. The position and screw-based Jacobian analyses of the CPM are presented by the authors and also, the compliance model and the workspace evaluation of the CPM. At the end of the paper, the integrated sensor is introduced and the authors conclude that static features of such a mechanism, include high positioning accuracy, structural compactness and smooth and continuous displacements.

In (Brookhuis *et al.,* 2012), the authors show a force sensor with capacitive readout is designed and realized for the measurement of mechanical power transfer. The authors state that the aim of the article is to integrate such sensors in a glove that will determine the complete mechanical interaction between the human hand and its environment.

In (Estevez *et al.*, 2012) the authors present the design, fabrication and characterization of a piezo resistive, 6 degrees of freedom (DOF) force and torque sensor to be used in micro-manipulation. According to the authors, the device has been fabricated with an IC-compatible process and contains 24 piezo resistors as sensing elements. The sensor partly asymmetric mechanical structure consists of 7 suspended beams providing force sensing functionality on a probing area, which includes a calibration structure. Due to this asymmetrical structure, micro-manipulation tools such as micro-grippers or probes can be easily implemented in the same substrate as the sensor, replacing the probing area.

In (Chen *et al.*, 2015) the development of a six-axis force/torque sensor, which could be used as a component for the large manipulator in the space station, is adressed. To obtain the large measurement range of force/torques, an elastic body based on cross-beam with anti-overloading capability is designed, and the size is optimized by using Finite Elements Analisys to guarantee both high stiffness and sensitivity of the six-axis force/torque sensor. The signal acquisition module which includes a high signal-to-noise ratio amplifier circuit is integrated in the sensor, so as, to be more reliable. Also, a novel calibration system is designed to provide large and accurate force/torque source. According to the particularity of the sensor's coupling errors, two decoupling algorithms are proposed in the paper to achieve high precision and flexible usage. The online decoupling algorithm is based on calculating decoupling matrices in partitioned space, while the offline algorithm is based on an optimized BP Neural Network using GA. According to the authors, experimental results show that the designed six-axis force/torque sensor works well with high precision and reliability.

In this paper, are proposed the calibration of a force and torque sensor, using neural networks in a general way. The calibration procedure proposed, involves the raw data acquisition of force and torque to feedback a neural network and the output of the neural network is a calibration matrix which, once multiplied by the sesnsor raw data, provides results in engineering units (N and N.m)

2. MATERIALS AND METHODS

2.1 Artificial Neural Networks

Artificial Neural Networks are computational techniques that present a mathematical model inspired by the neural structure of intelligent organisms and acquire knowledge through experience.

A large artificial neural network can have hundreds or thousands of processing units; already the human brain can have many billions of neurons. An artificial neural network is composed of several processing units, whose operation is quite simple. These units are usually connected by channels that are associated with a certain weight. Units make operations only on your local data, which are inputs received by your connections. The intelligent behavior of an Artificial Neural Network (Fig. 1) comes from interactions between the network processing units.

The operation of a processing unit, proposed by McCullock and Pitts in 1943, can be summarized as follows:

- Signs are displayed at the entrance;
- Each sign is multiplied by a number, or weight, that indicates its influence the output of the unit;
- The weighted sum of the signals produced by a level of activity is made;
- If this activity level exceeds a certain threshold, the unit produces a output response.

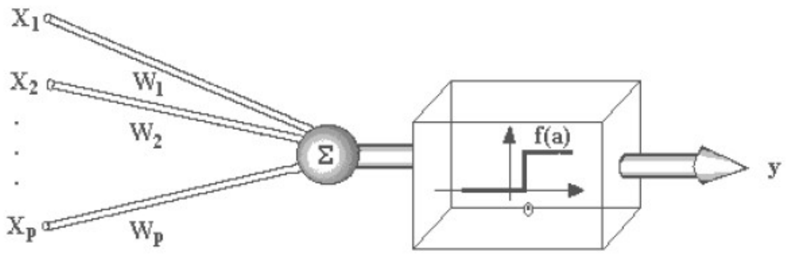

Figure 1 - McCulloch - Pitts Neural Networks Schematics

2.2 Force and Torque Sensors

The force an torque sensor, respond to the applied forces, according with Newton's third law which states that for every action there is always a opposed or equal reaction, or, the mutal action of two bodies upon each other are always equal, and directed to contrary parts. Figure 2, shows the force and torque vectors applied to the transducer.

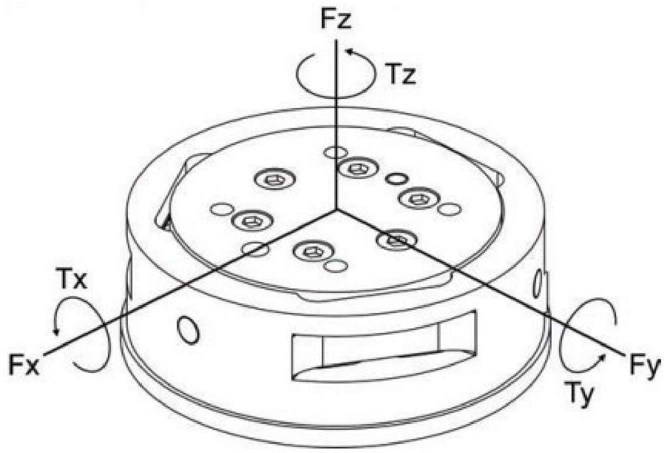

Figure 2 – Applied Force and Torque Vector on transducer

The force applied to the transducer, flexes three symmetrically placed beams using Hooke's law (Eq 1).

$$\sigma = E\varepsilon \quad (1)$$

Where:

σ is the stress applied to the beam, which is proportional to force;

E is the elastic modulus of the beams (Young's Modulus)

ε is the strain applied to the beam.

So the transducer output are 6 voltages, representing Fx, Fy, Fz, Mx, My and Mz, respectively. Once we have a calibration matrix, we can transform this voltages measures in engineering measures of forces, in Newtons and torques in Newton×meters.

3. EXPERIMENTAL SETUP

Now a days there is a sensor of force and torque, ATI gamma 3805 (Fig. 3), in the University laboratory, which needs an obsolete VISA board standard to operate. These kind of board should be put in a slots which is very difficult to find in computers PC compatible today. Fortunately, between the sensor and the PC computer, there is a DB-15 connector, which allows us to intercept the sensor output, treat, calibrate and record it.

So this work starts with the objective to use this sensor, which is a very precisely one, in anu computer PC compatible. To do so, we needed to recalibrate the sensor because its calibration was done by a manufacturer software, which directly access the sensor, only via the obsolete VISA board.

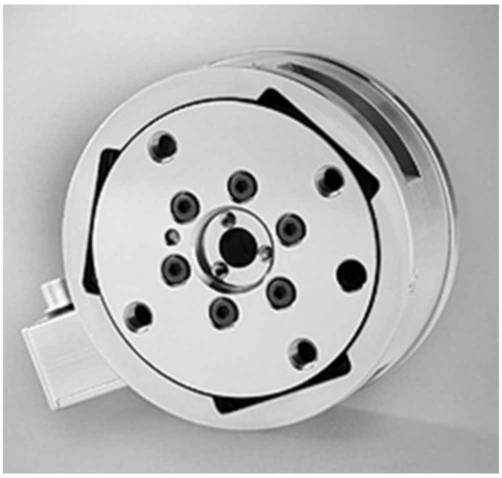

Figure 3 - Force and torque sensor, model gamma 3805 - ATI Industrial Automation

In order to recalibrate the force and torque sensor, was assembled an experimental setup, composed by the force and torque sensor manufactured by the ATI Industrial Automation and a data acquisition board NI MyDaq manufactured by National Instruments. The sensor is capable of measuring forces up to 65 N and torques up to 6.5 Nm.

The data acquisition board has available two voltage outputs with ± 15 Volts and two differential channels of analog input (both necessary for reading the data) and 16-bit resolution, ensuring data with high accuracy. To control all the hardware assembled, was used the software LabView.

Finally, on top of the sensor, we mounted a support (Fig. 4), based on the weight loading system developed by Liang, Q. et all. (2010), in order to input the sensor with known forces and torques.

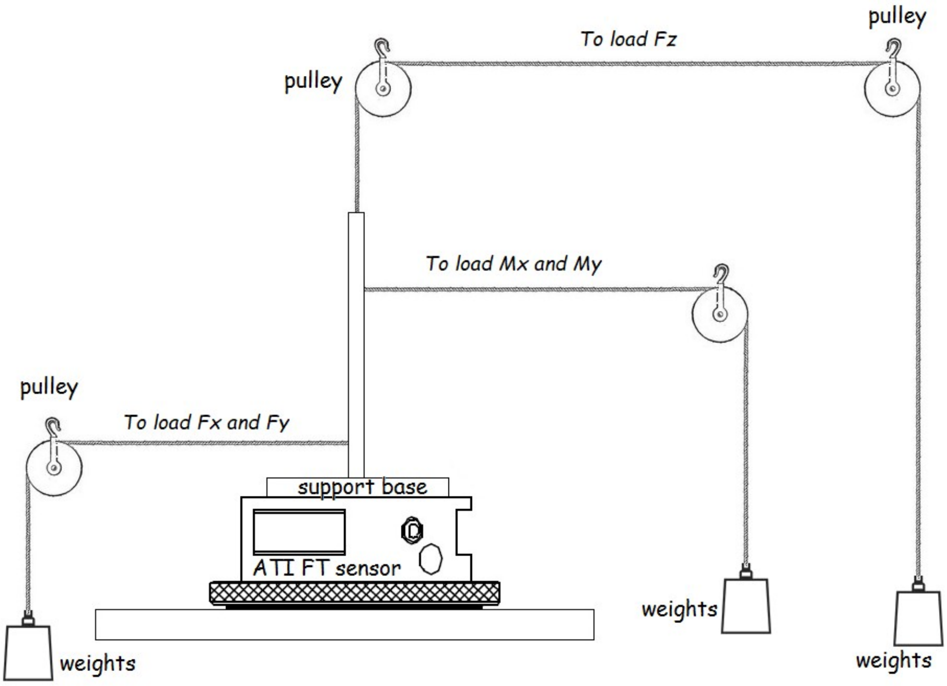

Figure 4 - Scheme of the support mounted on top of the sensor

The experiment allows the excitation of forces and torques in all axes at once. So the values to be read by the sensor could be easily calculated from the physical laws governing the system. The LabVIEW software was used to acquire the raw values of voltage, corresponding to the sensor outputs. The collected samples served as inputs to the neural network implemented. The developed neural network is the MLP type, and its architecture is shown in Fig. 5.

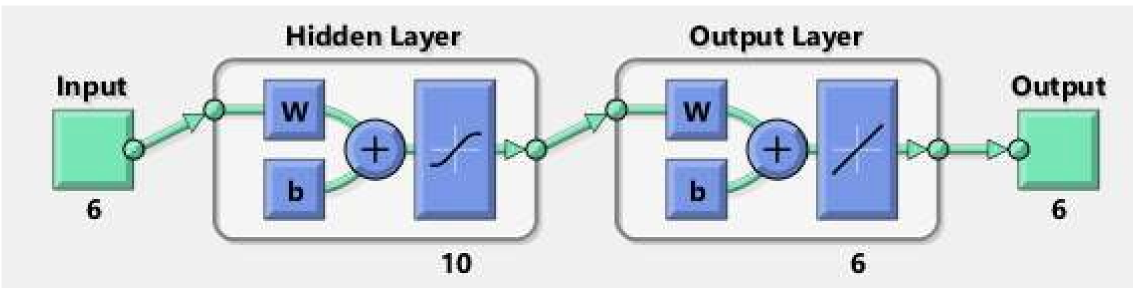

Figure 5 – Neural Network architecture

It has the raw values of voltage obtained experimentally like the six corresponding entries. Ten neurons in the hidden layer or intermediate six neurons in the output layer, corresponding to three values of voltage and three power values. The chosen training algorithm was the Levenberg-Marquardt, since it showed the best results. The available data were divided as follows: 70% for training, 5% for validation (since the data were obtained experimentally and need not be validated) and 25% for testing. The MATLAB software was used to implement the neural network and pos process the data. The toolbox known as "Neural Network" (Fig. 6) proved to be quite useful for simplifying the assembly of the network.

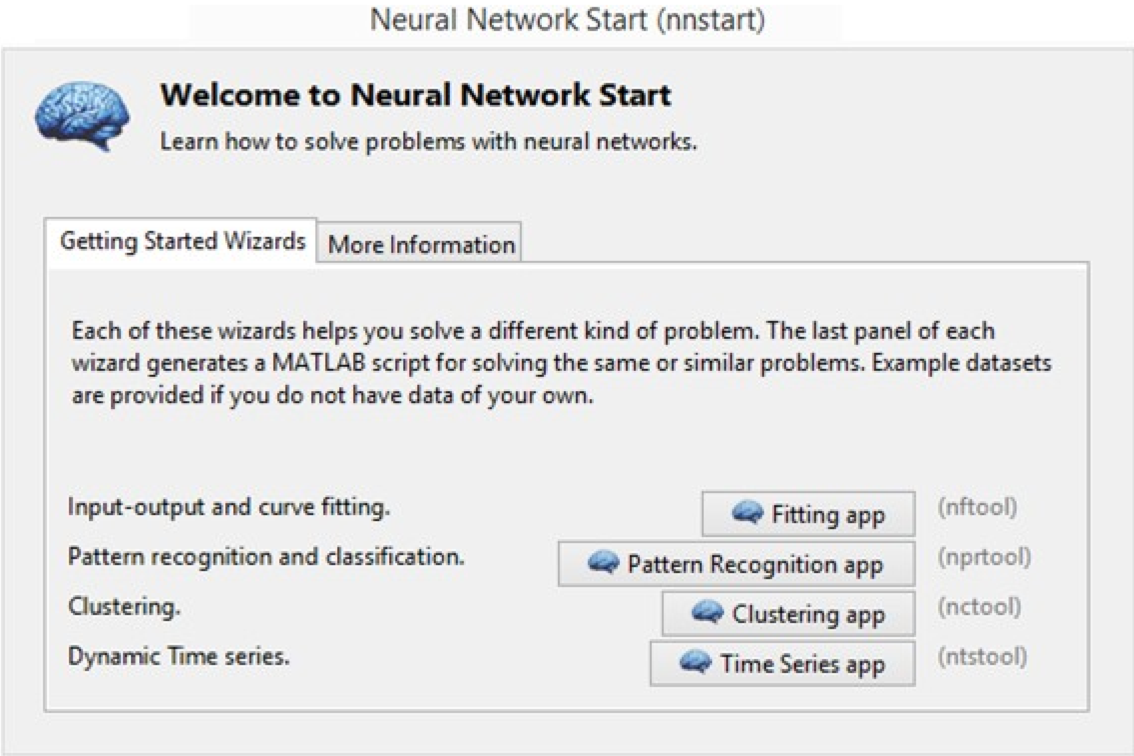

Figure 6 – Neural Network toolbox

4. NEURAL NETWORK RESULTS

From tests performed on the generated neural network, the following graphs were obtained: error histogram (Figure 7), which compares the actual value obtained by the neural network and distribute this error graphically in order to illustrate the average error committed; and linear regression (Figure 8), which graphically compares the value of the results found and expected and traces the curve corresponding to function describing the system behavior.

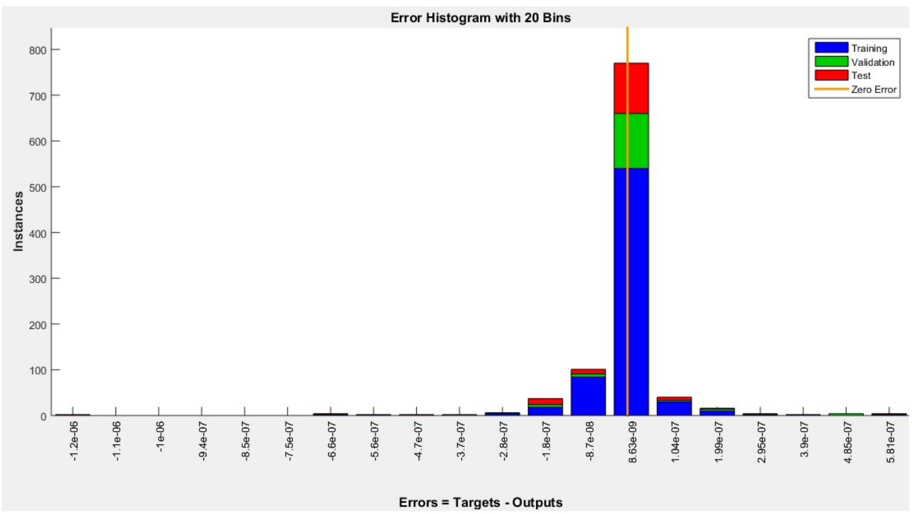

Figure 7 – Error histogram

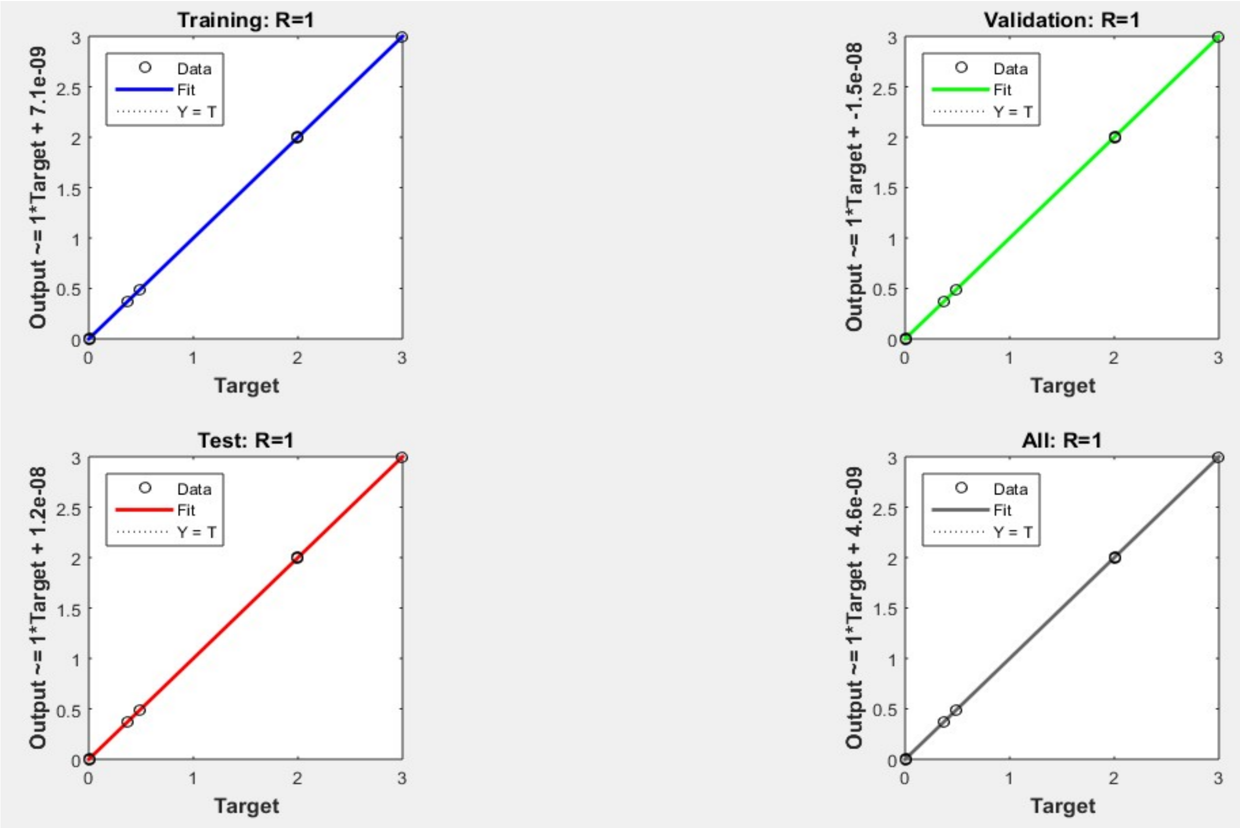

Figure 8 – Linear regression

From the graphs generated, it can be concluded that the network is able to portray the system within the expected behavior, with minimum and somewhat negligible errors.

5. DISCUSSION OF THE RESULTS

The sensor used in this work was initially designed to work with a VISA board, but because the conditions of the sensor we opted to use data acquisition board NI MyDAQ. The manufacturer recommends a calibration matrix to use of the sensor, which did not work due to differences of the data acquisition board and sensor state.

The calibration matrix demonstrates a linear behavior, which first induce the use of a perceptron network. After testing the network realizes the non-linearity of the sensor (probably due to their condition). Therefore necessary to adopt a MLP type network.

If the available sensor was in perfect condition, probably a network perceptron will be sufficient for calibration, since a calibration matrix would be sufficient. In addition, the array weights could be set separately, since they would not influence each other

6. CONCLUSIONS

In this paper, we developed a method for calibrating a force and torque sensor using the help of neural networks. The method was able to overcome incompatibilities and situations not covered by the manufacturer of the sensor, such as using a different data acquisition board expected by the manufacturer and the sensor conservation state.

We believe that the method developed is capable to calibrate the sensor solving the vast majority of situations not covered in your manual in a fast and practical way.

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