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DESIGN OPTIMIZATION OF CONTACT FORCE SENSOR

P. Krejčí*, R.Vlach, R. Grepl

Summary:

1. Introduction

The information about interaction between robotic parts and surroundings is necessary for intelligent control of robot behavior. This research is connected to research of contact force vector sensor principle and verification of its functionality which was performed in last year. Basic principle of sensor is based on measuring the strain in three locations by three strain gauges on active part of sensor. Based on these strains the contact force vector is identified by neural network. Huge matrix of training pairs is necessary for proper function of neural network. The training matrix contains pairs of strains in three locations and force vectors corresponding to sensor body strain. FE model of sensor was used to generate the training matrix. The research of this year was focused on further optimization of sensor body with ambition to improve its sensitivity for loads in all directions. The paper describes optimization procedure of sensor body as well as results of experimental verification of optimized sensor functionality.

2. Results of sensor optimization

During the previous research the worst sensor sensitivity was observed in axial direction. Therefore sensor optimization was focused on increasing of sensitivity for load applied in this direction (Krejčí, Vlach, Grepl , 2007). New optimization procedure was done for increasing the sensitivity in other directions. This optimization was extended to 2 steps for load forces oriented in different directions. The first step of optimization procedure is done for axial load of sensor head while second step is done for radial load. The result of optimization is shown for volume reduction of 80% in Fig. 2. The figure shows distribution of pseudodensity in sensor body. The boundary conditions used during optimization procedure are shown in Fig. 1.

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* Ing. Petr Krejčí, PhD, Ing. Radek Vlach, PhD, Ing Robert Grepl, PhD: Institute of Solid Mechanics, Mechatronics and Biomechanics, Brno University of Technology and Centrum of Mechatronics, IT AVCR, 616 69 Brno, Czech Republic, krejci.p@fme.vutbr.cz, vlach.r@fme.vutbr.cz, grepl@fme.vutbr.cz

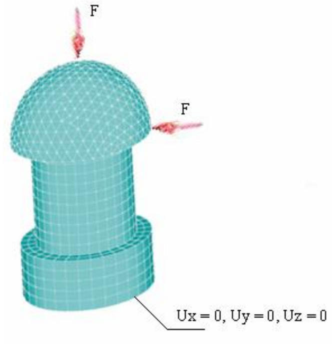


Fig. 1 Loads of sensor used in topological optimization procedure

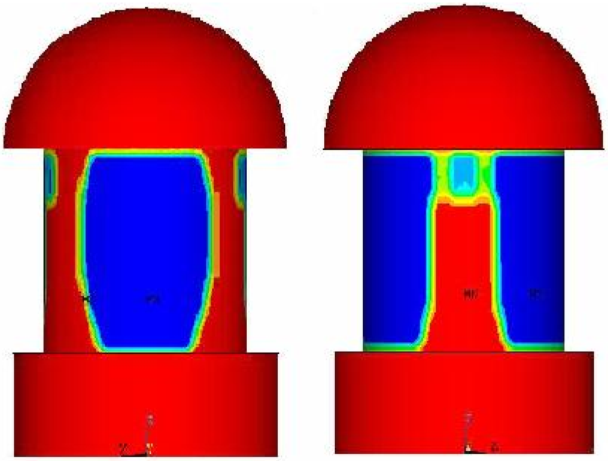
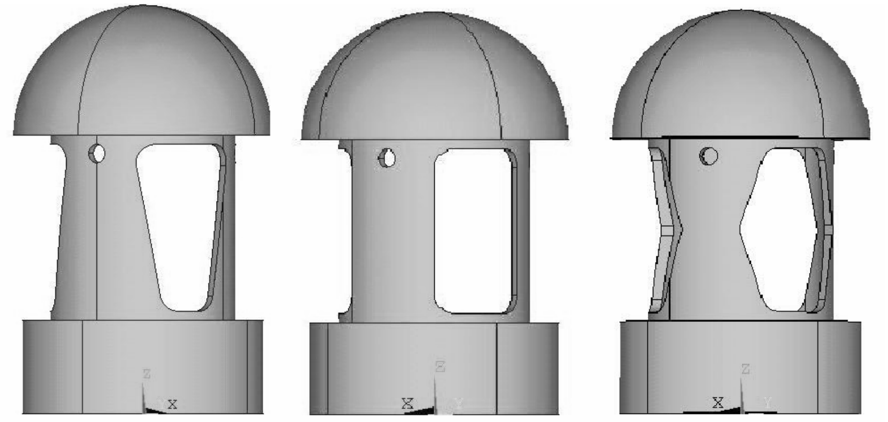


Fig. 2 Results of optimization

Optimized shape of sensor body need to by simplified by reason of good manufacturing. Due to this fact few shapes of cutting was designed with consideration of optimized shape and machining. Based on results of structural analysis rectangular shape of cutting with 1 mm hole (Fig. 3 b)) produces the best results in terms of sensitivity. This shape is also suitable for simple machining. Fig. 4 shows prototype of optimized and non-optimized sensor which is made from aluminium alloy.



a) b) c)

Fig. 3 Optimized sensors with different shapes of cuttings

Fig. 4 Optimized and non-optimized sensor prototype

3. Structural analysis of sensor prototype

Structural analysis of sensor was done in order to find out load limits where the linear behavior of structure occurs. Results of this simulation are shown in Fig. 5 for load force of *140N*. This value defines upper bound of sensor limits where plastic deformation of sensor body can occurs.

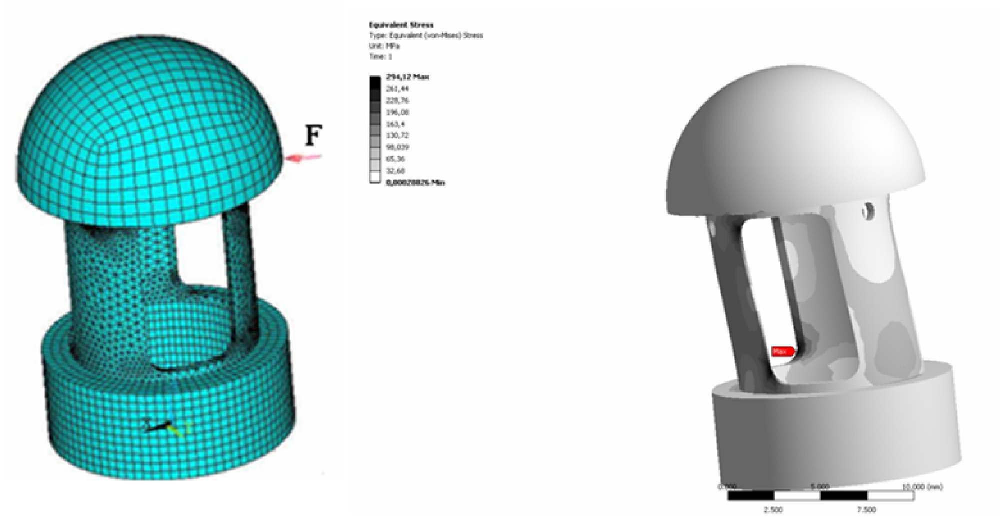


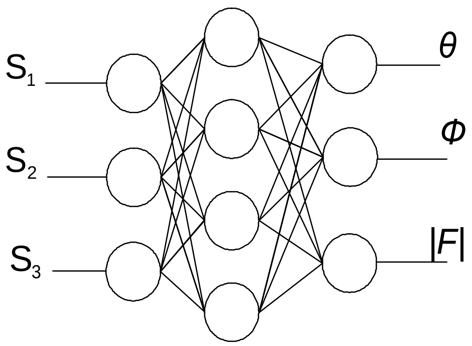
Fig. 5 Von-Misses stress of sensor for load of 140 N applied in radial direction

4. Verification of optimized sensor functionality

Functionality of optimized sensor was done by two methods. Finite elements model of sensor is used for calculation of body deformation caused by specified load in first method. The Second method using experimental verification of sensor subjected to real load. Deformations of sensor body observed by both methods are used as inputs of neural network which produces information about contact force magnitude and coordinates.

Neural network

The architecture of artificial neural network (ANN) is shown on Fig. 6. The input vector contains deformations of sensor body measured by strain gauges or calculated by numerical simulation of FEM model of sensor. The output vector contains information about contact force magnitude and coordinates of contact force in spherical coordinate system. The head of sensor has spherical shape therefore the spherical coordinates was used.



Where S1, S2 and S3 are deformations of sensor body
|*F*| is amount of contact force and
θ and *Φ* are coordinates of contact force in spherical coordinates

Fig. 6 Neural network

FEM model of sensor and calculation of deformation was used for creation of training matrix. The force oriented in perpendicular direction to sensor head was used as load of model for creation of each training pair. Load points used for generation of training data are shown in Fig. 7

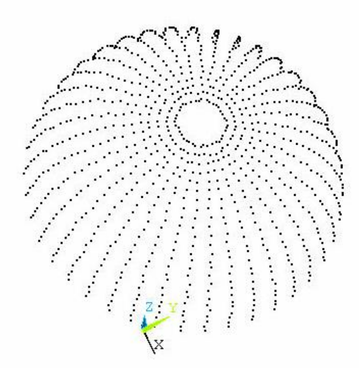


Fig. 7 Points of model load

Verification of functionality by FEM simulation

Sensor functionality was proof by numerical simulation using FEM model of sensor. The simulation also proofs accuracy of trained neural network, which was implemented in Matlab software.

The force of 20N applied on sensor head was used for the verification of ANN functionality. The position of the force was different than forces applied for ANN training. Calculated deformation in position of strain gages was used as inputs for neural network which produces coordinates of force used for simulation. The maximal difference in load force position between force coordinates used for FEM model loading and simulated coordinates retrieved from ANN was up to 2%. This difference also shows error of trained neural network.

Experimental verification of functionality

The sensor functionality was also verified by experimental simulation in laboratory of Mechatronics. During experiment the loads of sensor was applied in several positions of sensor head. Gauging fixture (Fig. 8) was used for sensor positioning. Load was applied by materials testing machine Zwick Z 020-TND (Fig. 9, Fig. 10) where the real load force was measured. The deformation of sensor body was measured by strain gauges through HBM Spider 8 unit which is among other things designed for measuring of deformation by strain gauges.

Fig. 8 Gauging fixture

Measured deformations are transferred to information about contact force position and magnitude by neural network implemented in Matlab software.

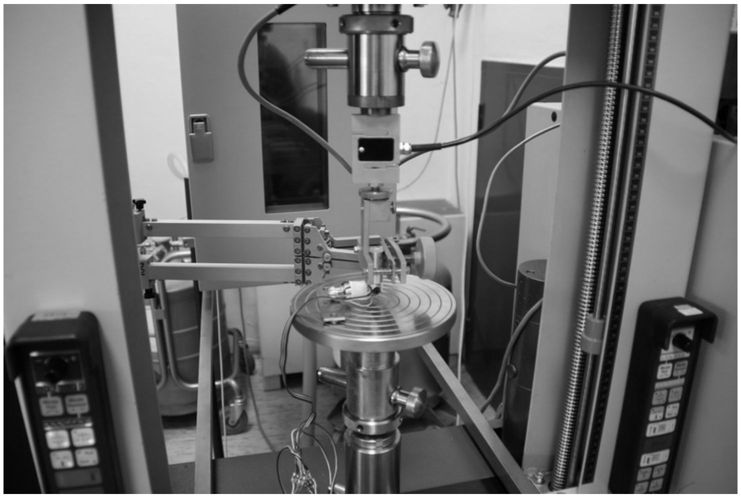


Fig. 9 Testing machine Zwick Z 020-TND

The results of experimental verification show that the maximum inaccuracy of sensor is up to 10%. This difference can be caused by inaccuracy in strain gauges application.

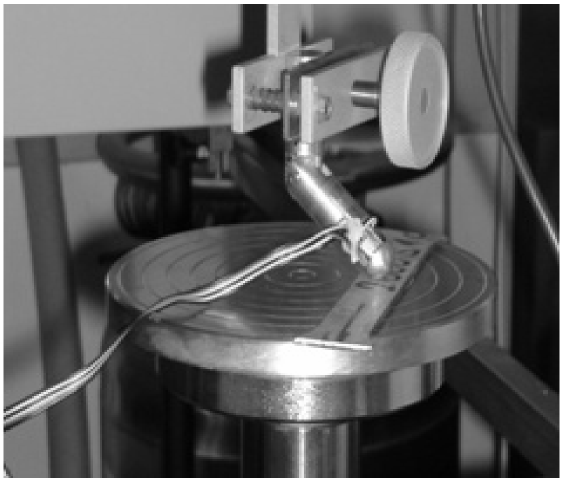


Fig. 10 Loaded sensor during experimental verification of functionality

5. Summary of achieved results

The optimization of sensor body was done in two steps for two forces oriented in different directions. Due to two step optimization procedure the sensitivity of sensor increased for load in all direction.

Experimental verification of sensor functionality also showed really good accuracy of ANN for force vector identification. Based on numerical simulation using FEM model of sensor the maximal load force of sensor was observed. The force of 140N is maximal limit of load in radial direction.

6. Acknowledgement

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