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Neuro-fuzzy estimation of passive robotic joint safe velocity with embedded sensors of conductive silicone rubber

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ABSTRACT

Robotic operations need to be safe for unpredictable contacts. Joints with passive compliance with springs can be used for soft robotic contacts. However the joints cannot measure external collision forces. In this investigation was developed one passive compliant joint which have soft contacts with external objects and measurement capabilities. To ensure it, conductive silicone rubber was used as material for modeling of the compliant segments of the robotic joint. These compliant segments represent embedded sensors. The conductive silicone rubber is electrically conductive by deformations. The main task was to obtain elastic absorbers for the external collision forces. These absorbers can be used for measurement in the same time. In other words, the joint has an internal measurement system. Adaptive neuro fuzzy inference system (ANFIS) was used to estimate the safety level of the robotic joint by head injury criteria (HIC).

1. Introduction

Robots as service agents mostly share working space with humans. This can lead to unpredictable collisions with some external objects or with humans. The most important task of the robotic designers is to avoid these unpredictable collisions or to ensure the collisions as safe as possible. Such a safety can be obtained through robotic joints improvement. One of the solution is to make robotic joints with additional compliance [1,2]. This compliant joints need to satisfy the safety injury criteria before their applications in real working space with humans.

There are several safety injury criterions. Head impact power (HIP) [3] is a criteria which provided with simulated injury monitor (SIMon) [4]. Louis Pasteur University (ULP) [5] is criteria which uses finite element head models. Head injury criteria (HIC) [6,7] is used to estimate the maximum allowed robotic joint velocity.

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HIC was used in [8] for one passive compliant mechanism for human friendly robotic. In [9] HIC assessment is established in regards to functional aspects. A combination of robotic joint with variable impedance was discussed in [10]. The variable impedance was used to ensure unpredictable collisions with humans and external objects in case of failure of sensing unit. One more case of application of robotic joint with internal elastic segments is presented in [11].

There are usually two typed of robotic joints: passive compliant joints [11–14] and rigid joints. Rigid robotic joints can provide high movement accuracy but contacts with external objects are usually hard. On the other hand, passive compliant joints can ensure smooth contacts with surrounding but the accurate measurement of positions of the joint members are not precise [15–17] since the joints have springs as internal elements which cannot be used for measurements. Therefore in this study the main aim was to implement conductive silicone rubber as sensing elements and elastic elements in same time. The conductive silicone rubber is composed of non-conductive elastomer and convictive elements [18]. In such a way the material has variable electrical resistance thought the external deformations. Also this material has elastic properties which can be used for smooth contacts between robots and external objects [19].

In this tidy the main aim is to estimate HIC on the developed robotic joint with conductive silicone elements. The HIC was used to estimate the highest safe robotic joint velocity in order to avoid injuries. As an algorithm for HIC index estimation, adaptive neural fuzzy inference system (ANFIS) was chosen since ANFIS has high adaptability and robustness on the measurement errors. ANFIS is composed of fuzzy logic and neural network. ANFIS was used in many engineering domains so far [19–34]. In this study the ANFIS training data was obtained by many experimental measurement of the robotic joint. Three statistical indicators were used to calculate ANFIS prediction accuracy: root mean square error (RMSE), Pearson correlation coefficient (r) and coefficient of determination (R^2).

2. Materials and methods

2.1. Robotic joint design

The structure of the robotic joint is shown in Fig. 1. This structure was used to measure electrical behavior of the embedded sensors [35,36]. Two parts of the joint can be noticed: external part and internal part. Also there are four embedded sensor implemented in the joint. The conductive silicone elements are positioned between these two parts of robotic joint. As the joint rotate the embedded sensors deform in regards to rotation direction. Two elements are compressed and the other two elements are relaxed in the same time. Fig. 2 shows two joint parts separated.

2.2. Design of sensors elements

2.2.1. Sensor elements for testing

Two sensor shapes are tested in order to determine which shape has the better characteristics of implementation in the robotic joint. These two shapes are cubic and cylindrical. The specimens are made of material Elastosil® R570/50, Shore A 50, by a press curing process as it is shown in Fig. 3. Electrical characteristics were measured of each of the sensor specimens.

Electrical resistance was measured for each sensor specimen to determine standard deviation of the electrical resistance. It was found that the standard deviation electrical resistance for all sensors was 144.75 before post-cure process and after the post-cure process the standard deviation was 12.99. This confirms that the electrical resistance of the sensors was stabilized after the post-curing process. Fig. 4 shows electrical resistance decreasing after the post-curing process for cubic and for cylindrical sensor elements.

2.2.2. Sensor elements for robotic joint

Sensor for robotic joint was designed in parallelepiped form according to these dimension (width = 9 ± 0.1, length = 15 ± 0.1, and height = 9 ± 0.1 in mm). The cylindrical shape was not chosen since the electrical resistance has high

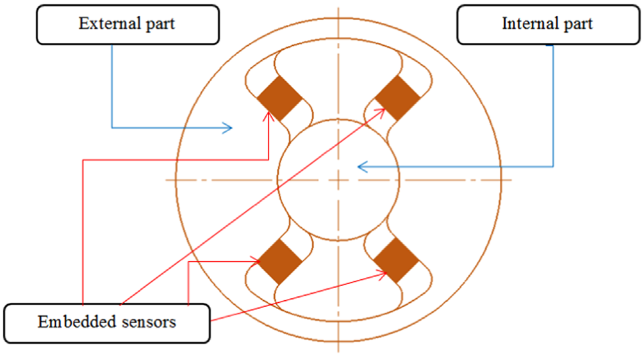

Fig. 1. Basic structure of the robotic joint.