The PRISMA Hand II: A Sensorized Robust Hand for Adaptive Grasp and In-Hand Manipulation

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Abstract—The PRISMA Hand II is a mechanically robust anthropomorphic hand, with a highly underactuated structure with 3 motors that drive 19 joints via elastic tendons. The mechanical design allows the hand to perform adaptive grasps and in-hand manipulation. Each fingertip integrates a tactile/force sensor based on optoelectronic technology, providing tactile/force feedback during grasping and manipulation, particularly useful with deformable objects. The abstract describes the mechanical design, sensor technology of the hand, and a calibration procedure for tactile/force sensors. Ultimately, an experimental session shows the effectiveness of the proposed calibrated sensors.

Index Terms—robotic hand, force/tactile sensors, neural networks models.

I. INTRODUCTION

Significant progress has been made in the development of anthropomorphic and dexterous prosthetic hands in the last few decades using different advanced technologies. Inspired by human hand, compliant designs are incorporated in robotic hand fingers to improve robustness on basis of a series of elastic tendon actuation and use of CORE (Compliant Rolling-contact Elements) joints, like the PISA/IIT SoftHand [1]. While the grasping capability of robotic hands is steadily improving and approaching human performance, the remaining gaps compared to the human hand are related to dexterity, particularly in-hand manipulation dexterity, mostly in presence of deformable objects. Recently developed fully-actuated hands, like the Bebionic Hand (Ottobock GmbH.) and the i-Limb Hand (Touch Bionics Ltd.), have demonstrated some level of in-hand manipulation dexterity, benefiting from independently driven finger joints. However, a fully-actuated hand is challenging in design, in particular, the major difficulty is to integrate a large number of actuators. Regarding tactile/force sensors, very few commercial devices are currently available integrating a force-sensing technology to improve the manipulation capabilities of the robotic hand. This paper presents a brief description of the PRISMA hand II and the tactile sensors integrated into it, presented in [2], [3] and shown in Fig. 1. Moreover, a calibration solution for all tactile sensors available on the robotic hand is proposed, and the solution compares different neural networks to evaluate their effectiveness through experimental validation.

II. MECHANICAL DESIGN

The PRISMA hand II has 19 joints and 3 motors, while each finger incorporates 3 flexion/extension joints consisting of compliant rolling joints. The thumb has a rotation and flexion joint controlled by motor 1 and 2 respectively, while the other fingers have one abduction/adduction joint controlled by motor 3. The finger flexion joints adopt the rolling contact joint, consisting of a pair of surfaces in rolling contact with each other, with elastic elements holding them together. Each joint includes a base link, a distal link, two ligaments, and a tendon. The ligaments are attached to the base link and the distal link, and the tendon, integrating elastic string, is anchored to the distal link and threaded through the hole of the base link. By pulling the tendon, the distal link is actuated and rolled on the cylindrical surface of the base link. Once the driving tendon is released, the elastic ligaments return the distal link to the extended position, similar to a torsional spring in a conventional pin joint. The flexible tendon and ligaments define the joint multidirectional compliance. It allows the definition of various disarticulations as backward bend, sideway bend, twist, and dislocation.

III. FORCE/TACTILE SENSORS TECHNOLOGY AND CALIBRATION

The PRISMA Hand II fingertips include tactile/force sensors, using LED-phototransistor couples, corresponding to the sensible points, organized as a matrix on a Printed Circuit Board (PCB), and exploited to measure the deformation of an elastic layer positioned above the optoelectronic devices. The PCB is constituted by four photoreflectors, each of which
integrates an infrared LED and a Photo-Transistor. The LED of each couple illuminates the reflective bottom surface of the silicone deformable layer, while the phototransistor receives the reflected light and transduces it into a current. When an external force is applied, the deformable layer produces some local variations in the bottom surface of elastic material, which induces a modification of the reflected light intensity and, consequently, an alteration of the current flowing into the phototransistor. The PRISMA Hand II motors and tactile sensors can also work on a Raspberry Pi® framework. The tactile sensors of the hand can read respective force values on the fingertips, and they are connected to Arduino® via I2C protocol which is further connected to Raspberry Pi® via USB. A calibration procedure allows obtaining a tactile map to estimate the force applied to the deformable layer. The sensor calibration identifies the parameters of a Neural Network model, which represents the relationship between the external applied force components and the raw voltage signals available from the sensor. Data are collected using the suitably prepared setup comprising of the developed fingertip sensor which is installed on a reference force sensor (ATI NANO 17 F/T Sensor) by an adapter. For each fingertip, the measurements have been recorded for about 180 s, by obtaining a total of about 30,000 data samples. The acquired data have been randomly divided into training, validation, and test subsets comprising 70\%, 17\%, and 15\%, respectively. The best-fitting results are obtained by using a fully convolutional neural network (FCN) and a convolutional neural network (CNN).

IV. EXPERIMENTAL VALIDATION

This section presents some experiments with the calibrated sensors assembled on-board the PRISMA hand II, to evaluate the effectiveness of the proposed sensing solution. The index finger of the PRISMA hand II has been used to push on the ATI NANO 17 F/T Sensor (used as ground truth for the calibration), mounted on a workbench (see Fig. 2). The objective is to compare the force reconstructed by the calibrated sensors using FCN and CNN models and the force components measured by the ATI sensor. Figure 2 presents the obtained results, showing that the FCN model has a good precision in following the ground truth trend on the z-axis direction compared to tangential direction forces (x,y). Instead, the CNN conserves a good precision in the trend in all three axial directions. Another test is done by placing the thumb on the ATI sensor and then let the pad sliding along the tangential directions (x, y). The norm of the force felt by the two sensors is computed, as shown in Fig. 3. The calibration of the fingertip sensors with CNN is more precise in following the trend of the ATI sensor in the sliding experiment along x-direction.

V. CONCLUSION

PRISMA Hand II possesses great potential to be developed as a multi-movement prosthetic hand to have grasping according to the objects by training a neural network. The tactile sensors providing adaptive grasping on the objects can make the patients feel more comfortable and not socially disconnected. For future works, the use of other neural networks known as SNN (Spiking neural network) can be explored, having the ability to act as a biological neural network. Furthermore, the hand can be controlled through EMG signals allowing the use of Augmented Reality Interfaces for testing and simulation.

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