Identification of hand postures by force myography using an optical fiber specklegram sensor

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ABSTRACT

The identification of hand postures based on force myography (FMG) measurements using a fiber specklegram sensor is reported. The microbending transducers were attached to the user forearm in order to detect the radial forces due to hand movements, and the normalized intensity inner products of output specklegrams were computed with reference to calibration positions. The correlation between measured specklegrams and postures was carried out by artificial neural networks, resulting in an overall accuracy of 91.3% on the retrieval of hand configuration.

Keywords: Force myography, fiber specklegram sensor, hand movements, human-system interface

1. INTRODUCTION

The force myography (FMG) analysis consists of measuring the mechanical efforts exerted by the forearm muscles in radial direction, in order to retrieve the effective movements – or intentions – and forces of human hand, wrist, and fingers[1]. Such information can be applied on the control of bionic prosthesis[2], as well as in rehabilitation systems[3]. The FMG can be defined as a mechanical counterpart of the surface electromyography (sEMG), but in contrast to the later one, it is less affected by the precise placement of sensor probes and the skin humidity conditions[4].

The FMG signals are usually assessed by force-sensing resistors (FSR) installed along a forearm orthosis[1]. Even though such devices yield reliable results, limitations in terms of drifts and vulnerability to electromagnetic interference can compromise the system performance in some applications[5]. An alternative to avoid such limitations consists in utilizing optical fiber sensors, due to their intrinsic characteristics[6]. Among the several schemes of photonic sensors for mechanical measurements, including intensity and spectrally based approaches[7], fiber specklegram sensors (FSS) can provide high-sensitive measurements (comparable to interferometric techniques) using a relatively simple interrogation setup[8]. In this research, the evaluation of a FSS for assessment of hand postures based on FMG analysis is reported. The fiber transducers are placed on the user forearm, allowing the measurement of muscular activities in response to variations in hand posture. Then, the specklegrams information are processed by artificial neural networks, making possible to retrieve the user hand configuration based on obtained data.

2. SENSOR DESIGN

2.1 Measurement system

The measurement apparatus is shown in Figure 1. The light emitted by a continuous 663 nm laser source is launched into the silica multimode fibers (62.5 μm core) by means of an alignment stage, being the waveguides subjected to a mode scrambler for balancing the modal power distribution. The modulation of transmitted light is carried out by microbending transducers installed along a 40 mm length fiber segment and placed over the user forearm. The deformer structures comprises of two layers of graphite rods (0.5 mm diameter) arranged in periodical fashion (5 mm periodicity), that interposes the waveguide. A 10 mm thickness polyurethane foam is attached to the transducer surface and acts as the interface between the deformer part and the subject skin. The pressures applied over the bending transducers due to the muscular activities induce light attenuations and variations in modal noise. Finally, the output specklegrams are recorded using a CCD camera (15 fps), and then post-processed by a routine developed under MATLAB environment.

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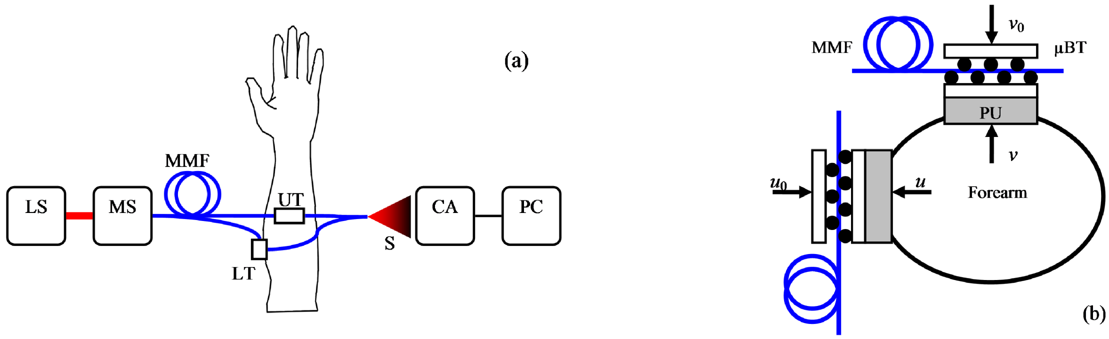

Figure 1. a) Measurement setup. LS: laser source. MS: mode scrambler. MMF: multimode fiber. UT: upper transducer. LT: lateral transducer. CA: CCD camera. PC: data acquisition and processing. b) Cross-section of forearm with transducers placement. μBT: microbending transducer. PU: polyurethane foam. u and v are related to the displacements on upper and lateral transducers, respectively, due to the forearm muscles, whereas u_0 and v_0 are the controlled preloads.

2.2 Specklegram analysis

The FSS consists in the analysis of modal noise for retrieving information concerning the fiber status. Given the light intensity $I(x,y)$ of a output speckle field projected over the xy plan of the CCD, the normalized intensity inner product (*NIPC*) of specklegram is calculated by

$$NIPC = \iint I_0(x,y)I(x,y)\,dxdy \Big/ \left[\iint I_0^2(x,y)\,dxdy \iint I^2(x,y)\,dxdy\right]^{1/2}, \qquad (1)$$

where I_0 is the intensity for a reference fiber status[8]. In practice, as I deviates from I_0 due to the mechanical disturbances, the respective *NIPC* decays from ~1 to a minimum value > 0. Such measurement is more sensitive than conventional intensity-based sensors, since the FSS takes advantage of modal phasing information. Moreover, the specklegrams are reproducible under certain conditions, i.e., *NIPC* value returns to ~1 as the mechanical stimulus is removed.

3. EXPERIMENTAL PROCEDURE

3.1 Measurement procedure

The experiments were conducted for 3 healthy individuals (~25 years old), with the subject sit in a comfortable position by placing his arm over a flat tabletop, with the elbow extended and the pronated forearm supported by a pair of polyurethane foam molds. The bending transducers are installed in the internal top and lateral parts of a mechanical stage, which clamps the forearm at ~15 cm distance from the wrist, by applying an adjustable preload. A detailed study about the transducers characterization and placement can be found elsewhere[9].

After receiving a visual command, the subject is requested to adjust the hand posture (Table 1) according to predetermined sequences of movements (repetition of A, B and X, where X is a posture from C to I), by maintaining each hand configuration for ~3.5 s, while the output specklegrams were recorded by the acquisition system. The *NIPC* were computed from the intensity values obtained by upper and lateral transducers regarding reference positions A (open hand) and B (closed hand), resulting in 4 *NIPC* curves per experiment.

3.2 Identification of hand posture

In order to evaluate the sensor performance on the retrieval of hand postures, a feed-forward backpropagation artificial neural network (ANN) was designed. The average *NIPC* values were calculated for each posture, and the reduced data were addressed to the network input, whereas the output was set to a pseudo-binary code relative to the hand configuration. The ANN also comprised 7 hidden layers of 50 neurons, adjusted with tangent sigmoidal transfer functions. The training step was carried out with part of the experimental data, by using the scaled conjugated gradient algorithm, and the network was subsequently tested for the remaining dataset. Finally, the ANN output was decoded for retrieving the corresponding posture, and the sensor accuracy was obtained from the ratio of correct detections.

Table 1. Selected hand postures for evaluation of fiber specklegram FMG sensor, and ANN performance on identification of each posture during training and test stages.

Postures	Description	ANN accuracy (training)	ANN accuracy (test)
A	Open hand with fingers joints extended	97%	97,5%
B	Closed hand with fingers joints flexed	100%	100%
C	Open hand with fingers extended and abducted/adducted	93,3%	80%
D	Open hand with index finger proximal interphalangeal joint flexed	86,7%	80%
E	Open hand with middle finger proximal interphalangeal joint flexed	100%	100%
F	Open hand with thumb interphalangeal joint flexed	93,3%	40%
G	Closed hand with index finger joints extended	93,3%	60%
H	Closed hand with index and middle fingers joints extended	100%	80%
I	Closed hand with thumb joints extended	100%	80%

4. RESULTS AND DISCUSSION

Figure 2 illustrates the normalized intensity and *NIPC* curves obtained by the specklegram sensor for a sequence of movements comprised of repetitions of postures A, B, and E, in which $NIPC_{AU}$ and $NIPC_{AL}$ are the *NIPC* for upper and lateral transducers, respectively, calculated regarding reference posture A, whereas $NIPC_{BU}$ and $NIPC_{BL}$ were evaluated for hand configuration B. In contrast to the intensity curves, which indicate mostly the mechanical forces applied over the microbending structures, the *NIPC* are highly correlated to the corresponding reference posture. In this sense, the *NIPC* assume higher values when the hand is adjusted according the reference condition, being reduced to lower values as the hand configuration is changed, since the variations on forearm muscles radial forces cause deviations on specklegram characteristics. The $NIPC_{EU}$ and $NIPC_{EL}$ were computed regarding posture E, as shown in Figure 2, for comparison purposes, which demonstrates that the *NIPC* can be calculated referenced to any hand configuration.

Concerning the transducers positioning, Figure 3 presents the correlation between $NIPC_A$ and $NIPC_B$ for upper and lateral transducers, where each point corresponds to the average of 3.5 s. The data for A and B are concentrated in opposite clusters, whereas the results for the other postures are distributed over intermediary $NIPC_A$ and $NIPC_B$ values. As the upper and lateral devices experience different forces during the realization of hand movements, since each deformer structure was installed to sense a certain group of forearm muscles, the *NIPC* values for a particular transducer present a higher correlation when the hand configuration activates the muscles monitored by that device. Therefore, the posture can be retrieved by combining the information from both transducers. In particular, the scattering observed for B values was caused due to grasping force variations during closing hand events.

Finally, the results for hand postures identification by ANN are summarized in Table 1. The network presented an overall accuracy of 97.4% and 91.3% for the training and test stages, respectively, therefore the methodology was capable to discriminate most of studied postures. The analysis of postures F and G yielded low accuracy probably because the *NIPC* values for such hand configurations were not sufficiently correlated to the reference postures. In this sense, the sensor response could be improved by utilizing additional transducers placed in different locations of the forearm, or eventually by performing a more intensive calibration procedure for the calculation of *NIPC* referenced to complementary postures. Such approach would be also necessary in case of analyzing an extended set of postures.

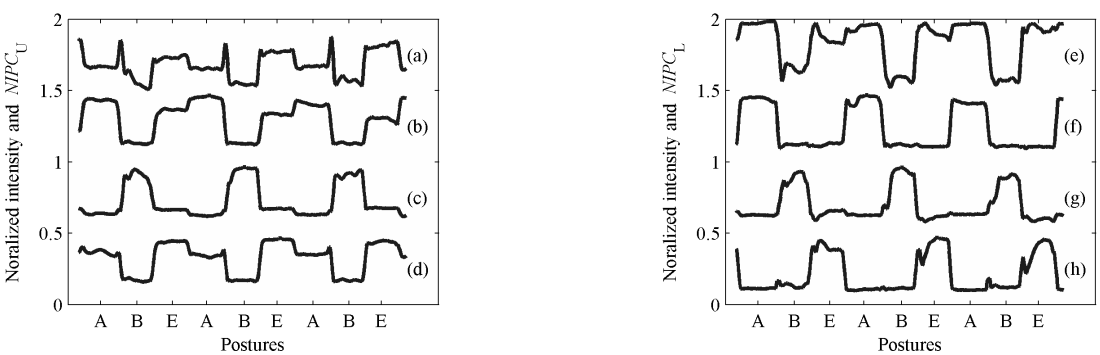

Figure 2. Sensor response to the realization of a sequence of movements. (a) and (e): normalized intensity for upper and lateral transducers, respectively. (b): $NIPC_{AU}$; (c): $NIPC_{BU}$; (d): $NIPC_{EU}$; (f): $NIPC_{AL}$; (g): $NIPC_{BL}$; (h): $NIPC_{EL}$.

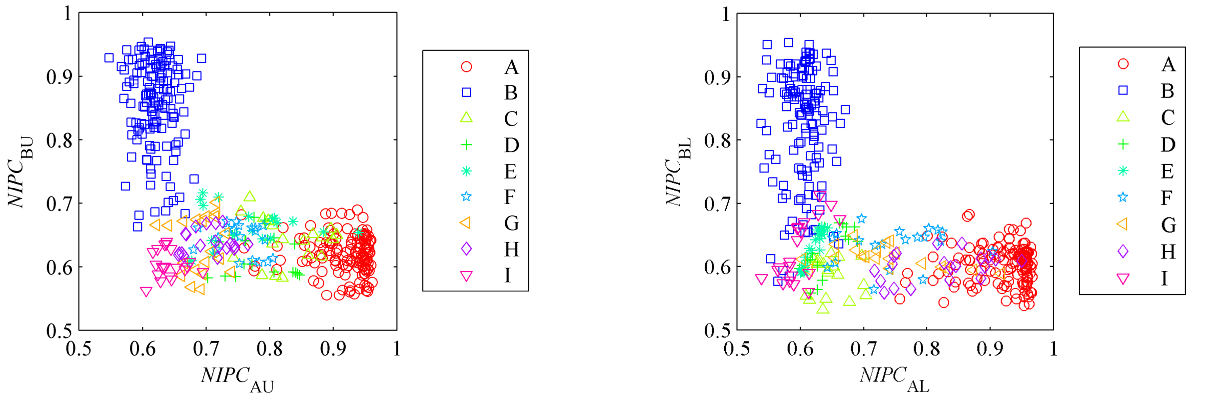

Figure 3. Correlation of $NIPC_B$ and $NIPC_A$ for different hand postures. Left and right graphs correspond to the results for upper and lateral transducers, respectively.

5. CONCLUSION

The assessment of hand postures by a FMG-based optical fiber sensor was demonstrated. The combination of specklegram analysis and ANN processing provided a relative good accuracy, even with the utilization of only 2 transducers and 2 calibration positions. However, in case of practical measurements, it will be probably necessary to include additional transducers for enhancing the discrimination capability and reducing the ambiguities. Further developments will be focused on the miniaturization and improvement of the sensor design, as well as on the integration of this technology to a glove-based sensor[10] for dynamic evaluation of hand movements and forces.

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