Functional Assessment of Hand Orthopedic Disorders Using a Sensorised Glove: Preliminary Results

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Abstract - The aim of this paper was to analyse the feasibility of using a sensorised glove as a tool for the assessment of hand function in persons with orthopedic disorders such as rhizoaarthrosis. A glove embedding 20 Hall-effect sensors was used for this purpose. Its performance in terms of repeatability were preliminary investigated in order to define an effective strategy for the use of the glove in these applications. After this preliminary phase, focused clinical experiments were carried out in order to verify the existence of differences usable for performance assessment in the postures of the hand of able-bodied and subjects affected by rhizoaarthrosis during grasping. The data were processed by using the Principal Component Analysis (PCA) technique. The preliminary results of these experiments showed that the use of the first and second Principal Components can allow to discriminate between able-bodied and disabled persons and also between disabled persons before and after the surgical intervention. For this reason, this approach could represent an effective tool for the surgeon during the rehabilitation process in this particular situation. Further experiments will be carried out in the future in order to confirm these preliminary results. Moreover, a new calibration procedure of the sensorised glove will be developed in order to improve the performance of the glove.

I. INTRODUCTION

Manipulation makes possible the interaction of human beings with the environment around them. The human hand, is a complex and adaptable system, capable of both delicate and precise manipulation and power grasping of heavy objects[1,2]. This is achieved by a combination of a large number of Degrees of Freedom (DoFs), a large number of proprioceptive and exteroceptive sensors, and a complex hierarchical control. However, despite of this complexity, the efforts required to everyone during the Activities of Daily Living (ADLs) are very small, even if unconscious and conscious training.

For its role, recovering hand function as fully as possible after traumas, lesions or degeneration is very important. Understanding the mechanisms used by Central Nervous System (CNS) to control manipulation is mandatory in order to define correct rehabilitation procedures aiming at restoring hand function compromised for different reasons.

Even if several classifications of grasp types have been performed in the past [3-6] few results have been achieved on the comprehension of the strategies implemented for the co-ordination of the fingers of the hand during manipulation. This situation is mainly due to the intrinsic complexity of the hand because of its high number of degrees of freedom. However, another important limiting factor is the difficulty of the state of the art motion analysis systems (based on the use of markers placed over the skin and used to track the movements by some cameras) in recording the movements of the fingers during grasping because of some drawbacks such as the problems in the calibration procedure and the disappearing of the markers during the movements.

The use of a sensorised glove for tracking hand trajectories could overcome some of these problems. This approach has been recently used with good results in some applications such as for the assessment of tremor in subjects affected by Parkinson’s disease [7] and for the development of rehabilitation strategies in stroke patients [8-9].

The aim of this paper was to verify whether this approach can be used to develop a tool for the analysis of hand function in people with orthopedic disabilities of the hand such as rhizoaarthrosis.

Rhizoaarthrosis is the localization of arthrosis to the trapezio-metacarpal articulation (TMA) of the thumb (see Figure 1). The trapezio-metacarpal is an articulation that presents a very complex saddle-shaped conformation that is itself prone to instability, but it is of the greatest importance for the movements of the thumb. The TMA permits, in fact, the opposition of the thumb to the others fingers and it is therefore mandatory in every grasp attitude of the hand (power grasp or precise manipulation). Arthrosis is a degenerative pathology of the joints, characterized by the damage of the cartilage wrapping the contact surface between two bones. This disease causes an impairment of the movements and often pain. For this reason, rhizoaarthrosis is a severe pathology from a functional point of view because it can reduce or even hamper the capability of carrying out ADLs. The treatment of rhizoaarthrosis is initially non-operative (anti-inflammatory drugs, ultrasounds, orthosis, etc.) and surgery is used only in severe cases.
The assessment of hand function is a fundamental task in this rehabilitation procedure. In this paper, the sensorised glove was tested in order to verify whether it is able to provide information about the differences between able-bodied and disabled subjects during grasping. Moreover, before using the glove in clinical experiments, the analysis of its performance in terms of repeatability was carried out in able-bodied subjects with a two-fold aim:
(1) to understand whether these devices (and particularly the system used in this work) are suitable for our purpose;
(2) to define a possible effective strategy for the use of the glove in these applications.

II. METHODOLOGY

A. The sensorised glove

During the experiments carried out in this paper, the trajectories of the different joints of the hand of the subjects were recorded by using the 20 Hall-effect sensors embedded in a commercial glove (Humanglove, Humanware srl, Pisa, Italy) shown in Figure 2. The size of the glove is given in Table 1.

The characteristics of the sensors of the glove are the following:
- resolution: 0.4 degree for all working range (12 bit A/D converters);
- linearity: ~1 % for all working range;
- accuracy: ~1 degree.

Table 1: Size of the sensorised glove

<table>
<thead>
<tr>
<th></th>
<th>Distal falanx (cm)</th>
<th>Medial falanx (cm)</th>
<th>Proximal falanx (cm)</th>
<th>Trasversal section (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thumb</td>
<td>3,4</td>
<td>4</td>
<td>5,7</td>
<td>1,5</td>
</tr>
<tr>
<td>Index</td>
<td>3</td>
<td>3</td>
<td>5,7</td>
<td>1,5</td>
</tr>
<tr>
<td>Middle</td>
<td>3,1</td>
<td>3,5</td>
<td>5,9</td>
<td>1,5</td>
</tr>
<tr>
<td>Ring</td>
<td>2,9</td>
<td>3,5</td>
<td>5,5</td>
<td>1,5</td>
</tr>
<tr>
<td>Little</td>
<td>2,5</td>
<td>2,5</td>
<td>4,5</td>
<td>1,5</td>
</tr>
</tbody>
</table>

The position sensors can provide information concerning the abduction and adduction of the fingers and the flexion and extension of the proximal, medial and distal parts of the fingers. The characteristics of the glove are quite similar to those of other devices already used in the study of hand biomechanics during grasp [10-11]. Moreover, in the first preliminary experiments the glove showed to be able to provide important information about the relationship between the different components of human prehension movements [11].

The sensorised glove allows a calibration of its sensors according to a two-step procedure:
(1) during the first phase the subject is asked to move all the joints in order to automatically obtain their range of motion. If the patient cannot carry out these movements voluntarily, this task is performed passively thanks to the help of an operator. This allows the development of a preliminary raw calibration comparing the information obtained with the normal range of motion of the different fingers in able-bodied subjects;
(2) the fine tuning of the calibration parameters is, then, carried out by comparing the differences between the actual posture of the hand and the one – obtained using the raw calibration - visualised on the screen of the PC using an OpenGL software.

Figure 1: The position of the joint which could be affected by rhizarthrosis

Figure 2: The sensorised glove
An example of the results achieved by using the software developed for the visualisation of the posture of the hand is given in Figure 3. The front-end designed for the calibration of the sensors is given in Figure 4.

### B. Protocol of the characterization experiments with able-bodied subjects (Phase #1)

In order to analyse the performance of the glove some preliminary experiments were carried out. Six able-bodied subjects (aged 24-30) participated in this study. In Table 2 the anthropometric data of these subjects are given.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Circ. Index</th>
<th>Lenght Index</th>
<th>Lenght Palm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Male)</td>
<td>6.6 cm</td>
<td>8.4 cm</td>
<td>11 cm</td>
</tr>
<tr>
<td>2 (Male)</td>
<td>6.9 cm</td>
<td>8.7 cm</td>
<td>11 cm</td>
</tr>
<tr>
<td>3 (Male)</td>
<td>6.7 cm</td>
<td>8 cm</td>
<td>11 cm</td>
</tr>
<tr>
<td>4 (Male)</td>
<td>6.8 cm</td>
<td>8.1 cm</td>
<td>10.6 cm</td>
</tr>
<tr>
<td>5 (Female)</td>
<td>5.6 cm</td>
<td>7.1 cm</td>
<td>8.5 cm</td>
</tr>
<tr>
<td>6 (Female)</td>
<td>6.2 cm</td>
<td>7 cm</td>
<td>9.2 cm</td>
</tr>
</tbody>
</table>

According to these information they can be tentatively divided into three different groups according to the size of their hands: (1) “big”: subjects #1,2; (2) “medium”: subjects #3,4; (3) “small”: subjects 5,6.

The subjects were asked to grasp the following objects:
1. sphere (diam: 6 cm), henceforth indicated as SF;
2. small cylinder (diam: 5.25 cm) henceforth indicated as CP;
3. big cylinder (diam: 6.75 cm) henceforth indicated as CG;
4. parallelepiped similar to a CD case henceforth indicated as CD.

Finally, the posture of the hand has been recorded also when the subjects were asked to close the hand in a fist (henceforth indicated as PC) and to have the hand completely open (henceforth indicated as MS).

The following procedure was implemented:
1. calibration of the glove donned by the subject;
2. grasping tasks #1 (ten times for each one);
3. re-calibration of the glove after its doffing and donning by the subject;
4. grasping tasks #2 (ten times for each one);
5. grasping tasks #3 (ten times for each one) after doffing and donning of the glove but with no new calibration.

### C. Clinical assessment experiments (Phase #2)

Three able-bodied female subjects (with no known hand diseases, aged 27-35, indicated as n1-n3) and five female subjects affected by rhizarthrosis with trapeziometacarpal sub-luxation (aged 66-78, indicated as s1-s5) participated in this study after providing informed consent.

Three of the five patients (s2, s3, s4) were treated (from two years to two months before the experiments) with a surgical intervention. The other two patients were selected and are still waiting for the surgery intervention.

Starting from a rest position (defined as the condition of electromyographic silence), the following movements of the hand were performed by the subjects:

1. thumb extension movement
2. thumb flexion movement
3. thumb abduction movement
4. thumb adduction movement
5. spherical grasp
6. cylindrical grasp
7. small pinch: grasping a pill
8. pulpar pinch: grasping a sheet of paper
9. “key” pinch: turning a key into the keyhole
10. tridigital pinch: using a pencil
11. “knife” pinch: using a knife
D. Analysis of the data recorded during Phase #2

The data were processed by using the Principal Component Analysis (PCA) technique which linearly transforms a set of initial variables into another reduced-dimension set of uncorrelated variables, e.g., the principal components [12]. The transformed variables are ranked according to their variance, thereby reflecting a decreasing importance as for their ability to capture the whole information content of the original data-set for signal reconstruction purposes. By virtue of its ability to reduce the complexity of the resulting feature space, the PCA has been widely used in a number of pattern recognition applications. Recently, it also played a role in the biomedical field, e.g., in the analysis of EMG signals [13] or for the analysis of hand posture during grasping "virtual objects" [10].

The PCs were calculated from the angular trajectories of the Degrees of Freedom (DoFs) related to the thumb movements of all the subjects.

III. RESULTS

A. Phase #1

The data recorded during Phase #1 were analysed in order to test the repeatability of the measures obtained using the glove. In Figure 5, the results of the intra-subject variability experiments for one subject are given.

Moreover, the Kruskal-Wallis test was carried out in Matlab (The Mathworks, Natick, USA) for a further analysis of the repeatability. The use of this particular test was due to the impossibility of applying the classical ANOVA test because the distribution of the data was proved not to be Gaussian.

In Figure 6, the values for the DoFs during the different tasks for subject #1 are given.

The results of these experiments on two different DoFs are given in Figures 7, and 8.
IV. DISCUSSION

The analysis of hand function in persons with different movement disorders is very important as it represents the first step the clinician has to address before defining the rehabilitation procedure for any patient. Because of the limitations of the state-of-the-art motion analysers in this particular case, the use of sensorised gloves is receiving a growing attention. In this paper a commercial sensorised system has been tested as a possible tool for hand function assessment. Before using the device in clinical experiments its performance have been analysed in able-bodied subjects.

The results of the Kruskal-Wallis test (in Figures 7 and 8) showed that for many subjects the glove was able to provide a quite good intra-subject repeatability. The worst results were obtained in case of subjects with “small” hands (see Subject #5 in Figures 7 and 8). This is due to the intrinsic difficulties of extracting good information when the anthropometric data of the subjects are too different from the size of the glove. Moreover, the limited inter-subject repeatability could be partly due to the intrinsic variability of the grasping strategies among persons.

Because of the drawbacks of the device mentioned above, the analysis in the clinical experiments was carried out by using a global index (which is probably more robust) instead of focusing the attention on a detailed analysis of the kinematic trajectories. For this reason, the Principal Components (PCs) have been calculated from the data recorded during several grasping tasks carried out by able-bodied and disabled persons. The first and second PCs were used because of their ability of explaining almost 70% of the variance of the time series. Moreover, the choice of using only two PCs can increase the possibilities of the clinician of extracting visual information by looking at the 2D plot.

In these preliminary experiments, the PCs proved to be able not only between able-bodied and disabled persons but also between persons who received a surgical intervention and persons who are still waiting for it. This interesting result could be used in the definition of the rehabilitation procedure. For example, if we consider the difference between the centroids of the two groups of disabled subjects as the effects of surgery, the clinicians can decide whether the intervention is necessary by looking at the position in the plane of the feature of the patient. If it is quite near to the centroid of the “after-surgery” group, they can decide to go directly to the
V. CONCLUSIONS

The preliminary results of this work seem to confirm the possibility of using the sensorised glove in order to extract information useful for the assessment of hand function in disabled persons. The limits of the performance of the device ask for the definition of a global index not so sensitive to the variability of the data recorded from the sensors. However, if these indexes are proved to be very useful to define the rehabilitation process, this could not be an important problem because in many situations the clinician is more interested in receiving global information than in looking at all the kinematic variables.

Future works will be in the direction of verifying the preliminary results illustrated in this paper during more extensive clinical experiments. Particular attention will be paid in order to understand which are the tasks more sensitive to the differences between able-bodied and disabled persons. This should reduce the discomfort of the subjects reducing the time necessary in order to carry out the assessment test.

Moreover, a new task-dependent calibration procedure of the sensorised glove (based on the application of soft-computing techniques) is under development in order to overcome the problems cited above. This algorithm should improve the performance of the glove.

Finally, new approaches to record finger movements are under investigation.

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