Static Analysis of Nippers Pinch
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Abstract
In the paper static analysis of two-fingered grip is presented. We have built a grip measuring device to assess the end point forces of the grip. Through the simultaneous use of the optical measuring system, finger positions and grip force acting on the object were obtained. A recursive computational method was used in the static analysis of the hand to calculate the joint torques of the fingers. The force output of the grip considered and the calculated joint torques are presented. Maximal values of finger joint torques acquired in the study are compared in two healthy individuals.

1. Introduction
The loss of hand's functionality from a central nervous system (CNS) injury or a hand injury can in a great deal influence a person's way of normal life [3, 5, 6]. Different methods of rehabilitation and therapy, including functional electrical stimulation (FES), can help such people regain a certain degree of functionality in their hands [5, 6].

In this research the static force analysis of human grasp was performed. A grip measuring device was designed to record the force vector acting on the object in two-oppositional grip [4]. Assessing the magnitude and direction of the fingertip force vector can provide additional information for the selection of stimulation patterns in FES of the hand [5]. The study is focused on nippers pinch which is characterized as precision grip [2, 4]. The grip is aimed to grasp and manipulate lightly weighted small objects (e.g. a pencil, paper clip), where the object is grasped between the finger pads of the thumb and the index-finger.

To retrieve finger positions during a grasp, optical measuring system was used. Hand and finger joints were marked with markers to capture their relative position to the object. Simultaneously the grip force was measured by the grip measuring device (GMD) developed. From the obtained results, finger joint torques were recursively calculated [1] by the use of the proposed static model of the human finger. The measured grip force and the joint torques were analyzed and compared in two healthy individuals.

2. Methods
2.1. Model
The three phalanges of the finger are modeled as rigid segments connected with joints [5]. Four degrees of freedom (DOF) were used to describe the movement of each of the two fingers. Universal joint (2 DOF) models the flexion/extension and add-/abduction of the proximal joint. Two rotational joints (1 DOF) are used to model flexion/extension of the middle and the distal joint. The approximate mass of the segments for an average male human hand was considered in calculations. The center of mass for each segment was determined by an approximation of the phalanx with a cone-shaped homogenous rigid body where the diameters of the knuckles were measured for each subjects.

2.2. Experiments
To calculate the finger joint torques, the measurements of fingertip force and position of the fingers, relatively to the object, are needed [1]. Hand posture in a grasp was assessed by the optical measuring system OptoTrak (Northern Digital, Inc.) which can accurately measure the position of infrared markers. Forces acting on the object were measured through a specially designed grip measuring device (GMD).

Fig. 1: Two-fingered grip assessment procedure was performed by use of the optical measuring system OptoTrak and a specially designed grip force measuring device (GMD).

Two sets of OptoTrak cameras situated in opposing direction were used. For convenience all marker data measured were transformed into a local coordinate system of the sensor (SCS), defined by the three markers on the surface of the device (Fig. 1). We also defined a hand coordinate system (HCS) on the dorsal side of the hand to
follow relative position of the hand to the GMD (Fig. 1). The rest of the markers were attached to the lateral side of the thumb and the index-finger to define the position of joints and fingertip (Fig. 1). The joint coordinate system of the segment $i$ (JCSI) was placed at the distal end of the segment as shown in (Fig. 1).

![Image](image_url)

**Fig. 2:** Grip measuring device (GMD) was designed to measure the end-point forces of the two-oppositional grip. The two metal parts, which shape into a circular stick to fit human fingers, allow the transmission of fingertip force to the sensory unit.

A grip measuring device was designed to measure the end-point forces of two-oppositional grip. The instrument is based on the robotic force-wrist sensor JR3 (JR3, Inc.). The GMD consists of two metal parts which are shaped in the form of the letter “L” with two semi-circular sticks attached to the frontal area (Fig. 2). When a person grasps the measuring stick the grip force is translated to the sensor. The force vector components were transformed into analog voltage values and sampled through the A/D unit of the OptoTrak to obtain simultaneously data of the grip force and positions of the finger joints.

### 2.3. Analysis

Recursive computational method [1] was used to describe forces and torques acting on the segments (Fig. 3) of the thumb ($k=1$) and the index-finger ($k=2$).

The equilibrium equations for forces, expressed in the coordinate system of the sensor, are written for each segment $i$:

$$ k \mathbf{f}_{i-1,i} - k \mathbf{f}_{i,i+1} + k \mathbf{m}_i \mathbf{g} = 0 $$

(Eq. 1)

Forces that act on the segment $i$ of the finger $k$ are: gravity force $k \mathbf{m}_i \mathbf{g}$, force $k \mathbf{f}_{i,i}$ describing the force of the segment $i$-$i$ acting on the segment $i$ and the negative force $k \mathbf{f}_{i,i+1}$ defining the action of the segment $i$+$1$ on the segment $i$.

Next, the equilibrium equation for the torques acting on the segment $i$ is written with regard to the center of a finger joint:

$$ k \mathbf{T}_{i-1,i} - k \mathbf{T}_{i,i+1} + k \mathbf{r}_i \times k \mathbf{m}_i \mathbf{g} - k \mathbf{r}_i \times k \mathbf{f}_{i-1,i} = 0 $$

(Eq. 2)

In (Eq. 2) $k \mathbf{r}_i$ connects the joint center with the center of mass for the segment $i$ and $k \mathbf{r}_i$ connects the joint center with the end of the segment $i$. The torque vector $k \mathbf{T}_{i,i}$ describes the torque of the previous segment onto the segment $i$. $k \mathbf{T}_{i,i+1}$ is the torque vector of the next segment acting on the segment $i$. The vector product $k \mathbf{r}_i \times k \mathbf{m}_i \mathbf{g}$ describes the effect of gravity force and $k \mathbf{r}_i \times k \mathbf{f}_{i-1,i}$ is the torque caused by the force $k \mathbf{f}_{i-1,i}$ acting around the origin.

![Image](image_url)

**Fig. 3:** Force and torque analysis of the $i$-th segment. Each finger was modeled as a set of rigid segments connected with joints.

The force $k \mathbf{f}_{i-1,i}$ and the torque $k \mathbf{T}_{i,i}$ are derived from the equations (Eq. 1 and Eq. 2). In the first step of the recursive computation ($i=4$) the negative force $k \mathbf{f}_{i-1,i}$ equals the force measured with the force sensor and $k \mathbf{T}_{i,i}$ equals zero. The calculation is then repeated for segments $i=3,2,1$ (from the tip to the palm) of both fingers $k=1,2$. In order to obtain the force and torque vector acting in the center of each joint, the calculated vectors were transformed to the corresponding joint coordinate systems.

![Image](image_url)

**Fig. 4:** Nippers pinch gives good sensory feedback allowing fine manipulation of small objects. Below is an example of the grip forces as assessed in the first subject. The maximal force component is perpendicular to the finger pads.

### 3. Results

The nippers pinch grip (Fig. 4) was performed by two right-handed healthy male individuals. Subject's hand was equipped with 11 infrared markers as described in the previous section. The GMD was rigidly attached to the table located in front of the OptoTrak cameras where the subject was seated on a chair with no additional support to the elbow.
The subject was instructed to perform the precision grip on the measuring stick with low (under 20N), medium (20 to 40N) and high level force (above 40N), keep it steady for a moment and then slowly release the grip. The whole session lasted approximately 6 seconds. In the paper the results of the mid-level grips are presented (Fig. 4 and Table 1). For each subject several attempts were made to obtain reliable results.

The calculated finger joint torques in nippers pinch for the thumb (above) and the index-finger (below).

4. Summary and Conclusion

The purpose of this study was to present the static analysis of a two-fingered grip. The OptoTrak system was used to capture the hand posture along with the grip measuring device which was aimed to measure the grip forces. From the data assessed the finger joint torques were calculated. The results were compared in two healthy individuals showing that the method can offer useful results for the analysis of human grasping, in particular after hand or CNS injury. The proposed method is similar to the part of the Fugl-Meyer hand evaluation test [3] used in the post-stroke hemiplegic patients.

With a modification of the GMD, grasps of different objects could be simulated. Various shaped end-point objects (e.g. in the shape of a disk, sphere, cylinder, etc.) could be used to replace the measuring stick in order to determine the forces which act on such objects in healthy and handicapped persons. The described testing method is intended to be used in connection with different rehabilitation therapies, including functional electrical stimulation (FES) [5, 6], to follow the improvement of a patient’s condition. The results obtained can be also used in the design of rehabilitative devices used for hand therapy of patients with CNS or hand injury.

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**References**


**Table 1:** The maximal values of the finger joint torques and the grip force components compared in the two subjects (S1 and S2). The results show that the load on the joints of the index-finger is considerably higher than the load on the thumb joints.

<table>
<thead>
<tr>
<th>Grip force (N)</th>
<th>Joint torques of the thumb (Nm)</th>
<th>Joint torques of the index-finger (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(F_x)</td>
<td>(F_y)</td>
<td>(F_z)</td>
</tr>
<tr>
<td>S1</td>
<td>1.3</td>
<td>-2.3</td>
</tr>
<tr>
<td>S2</td>
<td>-1.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Fig. 5:** The calculated finger joint torques in nippers pinch for the thumb (above) and the index-finger (below).