Hand grasp: analysis and experiments

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Abstract

This paper studies forces in the material handling equipment and evaluate the design and use of joysticks by a new generation of virtual humans (Santos\textsuperscript{TM}). The Denavit-Hartenberg method is implemented to analyze the 25-degree-of-freedom (DOF) hand model of the virtual humans. Human performance measures (joint torques and joint displacements) are criteria for the design of joysticks in the material handling machines. Finally we compare these analytical results with experiments with n=17.

Introduction

There are various injuries related to material handling. Especially, when the operator repetitively uses the joystick for long time, the operator’s hand will have problems. Therefore, to avoid this type of injury it is important to consider the ergonomic aspects of joysticks in the design stage.

The Santos\textsuperscript{TM} hand is a 25-DOF model \cite{1} and the parametric length for each finger and bone is used \cite{2}. In \cite{3} the same length was modified and adapt for simulated different tools.

\cite{4} presented fingers of a multi-fingered robot hand that touches an object. Sometimes the hand is modelled with spherical sensors.

There are different studies that analyzed the forces for all the fingers when the hand grasps a cylinder or other objects \cite{4-8}. However, to our knowledge, nobody has used mathematical hand model to guide joystick design.

This paper presents a new hand model to facilitate joystick ergonomic design. The nomenclature will first be introduced. Next the hand kinematics model is investigated. Finally, the strategy of hand grasping for a cylindrical object in virtual world is developed followed by the joint torque prediction to measure the design of the joystick.

The hand has 27 bones, where 8 small bones are distributed in the wrist, and the other 19 bones are distributed in the five fingers. Each finger has one metacarpal bone (the palm) and index, ring, middle and little fingers have three phalanxes (proximal, middle, distal) while the thumb has two phalanxes (proximal and distal). The bones connect one with another via joints. There are two types of movement called troquelar (move in one direction) and condylar (move in two directions). This movement is similar to a hinge and has one DOF.

To simulate the most realistic movement the hand model has 25 DOFs and the detail is shown in Fig.1.

Although there are many different ways to grasp a cylindrical object, the two major ones are grasping with power and precision. The task to grasp a pen from the table is one example for grasping with precision, while normally two fingers are involved in the grasping with the thumb and index in opposition. Of course, when one writes he/she can use two, three or four fingers.

Grasping a joystick is one example of grasping with power where normally four fingers (index, middle, ring and little) are involved in the grasping. Fig. 2 shows the configuration of this grasping.

Fig.3 depicts a schematic representation of fingers’ positions except the thumb. When a person grasps a cylinder, in general, from observations the position of thumb stays in the neutral position. Furthermore, the proximal phalanx bones are tangential with the cylinder. Without lost generality, we assume the contact points are located in the middle of these bones.
Materials and experimental methods

The experiments are doing with a n=17 persons, 11 women and 6 six men. The questionnaire is based in descriptive occupational methods. Ages of participants are between 25 and 72 years old. 6 haven some diseases in your hands, like arthritis, carpal tunnel syndrome, and diseases in the first metacarpophangeal joint (MCP).

Fingers joint torque

The relationship between the joint torque vector and end-effector force/moment vector is then given by

$$\tau = J^T F$$

(1)

where the torque vector is $$\tau = [\tau_1, \tau_2, \ldots, \tau_n]^T$$.

Now, we extend this formulation to the case where multiple external loads (both translational and rotational) are applied to any location of any finger/link, not necessarily to the end-effector. Let’s assume that a general form of external load $$F_k$$ is applied to the point at $$r_{k}$$ location of finger segment k, where $$k$$ location vector is expressed with respect to $$k$$th local coordinate frame.

This point of application of external load can be regarded as the end-effector for the corresponding external load. The augmented Jacobian matrix $$J_k$$ for this point is derived from the linear relationship between the joint velocity vector and the Cartesian velocity vector:

$$J_k(q) = \begin{bmatrix} \frac{\partial T_i(q)}{\partial q_1} r_k & \cdots & \frac{\partial T_i(q)}{\partial q_i} r_k & \cdots & \frac{\partial T_k(q)}{\partial q_k} r_k \\ Z_0(q) & \cdots & Z_{i-1}(q) & \cdots & Z_{k-1}(q) \end{bmatrix}_{6xk}$$

(2)

where $$Z_{i-1}, i = 1,\ldots, k$$ is the local z-axis vector of joint $$i$$ expressed in terms of the global coordinate system.

So the joint torque vector due to the external load applied at point $$r_k$$ of link k is

$$\tau_k = J_k^T F_k$$

(3)

From the principle of superposition, the total joint torques due to several external loads are obtained as a sum of all joint torques:

$$\tau = \sum_k J_k^T F_k$$

(4)

Figure 5 depict the joint torque for a several diameters of cylinders, calculate with the equation (4).
### Results and discussion

Figures 5 and 6 depict the means for the right and left hand. In questionnaire we ask for the dominant hand and 100% of participant has the right hand dominant. If we take a look to figures 6 and 7 for right hand, depict in position 2 (diameter 37.5 mm) the maximum force close to 30 N and when the diameter is more big, then the force exerted for the participant is more less that the previous diameter. Similar for left hand, but in this hand the maximum force exerted is in small diameter.

Figure 6: Mean Right Hand Force

![Right Hand Force](image)

Figure 7: Mean Left Hand Force

![Left Hand Force](image)

Table 1: Mean and Standard Deviation Forces

<table>
<thead>
<tr>
<th>Position</th>
<th>Right Hand</th>
<th>Left Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>24.00</td>
<td>11.73</td>
</tr>
<tr>
<td>2</td>
<td>28.50</td>
<td>12.57</td>
</tr>
<tr>
<td>3</td>
<td>24.00</td>
<td>11.42</td>
</tr>
<tr>
<td>4</td>
<td>20.00</td>
<td>10.46</td>
</tr>
<tr>
<td>5</td>
<td>18.00</td>
<td>9.37</td>
</tr>
</tbody>
</table>

Table 1 depict the mean and standard deviation (SD) for all the participants related with each position and each hand.

If we compare figures 6 and 7 with figure 5 the relationship between these figures is in the force that all the participants exerted for grasp and the force that we need exert in each joint, in each finger. Figure 5 depict the force augmented with the diameter, that means if the diameter is big we need exert a big torque and vice versa, and when grasp a cylinder figures 6 and 7 we exert this force, we have a big force in the joints, but small force in grasp.

### Conclusion

Virtual human hand grasping is proposed for joystick ergonomic design. Santos™ is a 101-DOF digital human model with 25 DOFs for each hand. Based on the hand model a grasping strategy is developed and joint torques are calculated to evaluate the design of joysticks in material handling machines. The experiment results illustrate the validity of the proposed grasping strategy for cylindrical objects. Human performance measures such as joint torques and joint displacements are the criteria to give the feedback from the virtual hands to test the design. Finally are compared the joint torques with the force exerted and read in the dynamometer with five positions.

### Bibliography


