A SYSTEM FOR MEASURING FINGER FORCES DURING GRASPING

T. Keller★★, M.R. Popovic★, M. Ammann★, C. Andereggen★, and C. Dumont★★

★Automatic Control Laboratory, Swiss Federal Institute of Technology Zurich
ETH Zürich / ETL K28, CH-8092 Zürich, Switzerland

★★ParaCare and Orthopedic Clinic, University Hospital Balgrist Zurich
Forchstrasse 340, CH-8008 Zürich, Switzerland

E-mail: kellert@balgrist.unizh.ch, popovic@aut.ee.ethz.ch

Abstract - *A device that provides quantitative assessment of the grasping function and allows the grasping function improvements to be monitored over time can potentially be very useful for hand surgeons, physiotherapists and occupational therapists. A Dynamic Grasping Assessment System (DGAS) that is capable of measuring finger forces during wrist extension, flexion, adduction and abduction was developed. The DGAS can measure forces for each individual finger in the range from 0 to 125 N with accuracy of ± 0.5 N, and can measure the wrist extension/flexion angle and the wrist ulnar/radial abduction angle with an accuracy of ± 0.25 deg. Furthermore the DGAS is capable of generating resistive torque during the wrist motion and allows to assess finger forces during wrist motion against resistive load. The DGAS can provide the following data: (1) finger forces as a function of time, wrist angle, wrist angular velocity and resistive load; (2) statistical analysis of the recorded finger force data; (3) drifts of the finger forces as a result of fatigue; and (4) the range of wrist motion for a given resistive load. Further analysis of the measured data, e.g. correlation analysis between the finger forces and the wrist angles, can be done off-line.*

Keywords: grasping, digital force measurement, quantitative assessment, strain gage force sensor

Introduction

Quantitative grasping assessment methods are either based on grasping skill tests or grasping force measurements. Grasping skill tests quantify the grasping performance using sets of objects that have to be grasped, moved and released. Grasping force measurements measure the force of the hand or the forces of each finger during a palmar or a pinch grasp. Both methods are used by surgeons, biomedical engineers, physiotherapists and occupational therapists to evaluate the improvement of the grasping function as a result of a surgery, physiotherapy, physical training, or the use of a grasping neuroprosthesis.

In the rehabilitation of spinal cord injured (SCI) or stroke subjects several grasping skill tests were proposed. In [1, 2] execution times for the grasping sequences were recorded. Objects with different sizes and weights were chosen appropriate to the limited grasping function of the subjects. Grasping skill tests assess very strongly the subjects' skills and training efforts, but give only limited findings about optimal placement of stimulation electrodes for the best grasping performance.

Another method to assess the grasping function is to measure the finger forces during grasping tasks. Simple devices like mechanical power-grasp dynamometers only measure the peak forces applied by all fingers against the palm. More sophisticated electronic dynamometers allow power- or pinch-grasp forces to be measured over time. by For example, the NK DIGITS-Grip™ device can determine the contribution of the individual fingers to the grasp. The tool consists of a electronic dynamometer with four additional finger force sensors.

A combination of functional and numerical assessment was presented by Riso [3]. He built a manipulandum that allowed the measurement of power- and pinch grasp and that could be loaded with different weights. Memberg and Craigo [4] developed so-called "instrumented objects". These were replications of objects used in activities of daily living. Force transducers were housed inside the objects and the subjects were asked to manipulate them. Examples are instrumented books using strain gages and instrumented sticks imitating a pencil or a toothbrush.

The presented dynamic grasping assessment system (DGAS) was developed for the assessment of the grasping force of each digit during wrist motion. Since every muscle produces different forces for different muscle lengths, a change in the finger flexion force can be observed for different wrist angles. The DGAS was constructed such that it is capable of measuring the wrist angle simultaneously to the grasping force of each finger and the thumb. The system can measure either flexion/extension angles and finger flexion forces or radial/ulnar abduction angles and finger flexion forces. The DGAS was built as a mountable platform for the BTE work simulator which is a device for the evaluation of the maximum strength, power and endurance of upper extremities. Using the BTE work simulator, the wrist rotation could be locked or loaded with resistive torque.

The aim of this first article about the DGAS is to give a full description of the DGAS and all its components. Further the mounting procedure and a description of the capabilities of the software are provided. First preliminary measurements obtained from 5 healthy subjects are discussed and compared with data from the literature.

Methods

The Dynamic Grasping Assessment System

To enhance the BTE work simulator with the capability of measuring the palmar grasp under different wrist moments and angles, four main parts were developed (see Figure 1):

1) A platform that is fixed to the head of the BTE work simulator
2) A grasping measurement device that allows an exact alignment of the grasping handle to the measured hand and houses an encoder for measuring the wrist angles

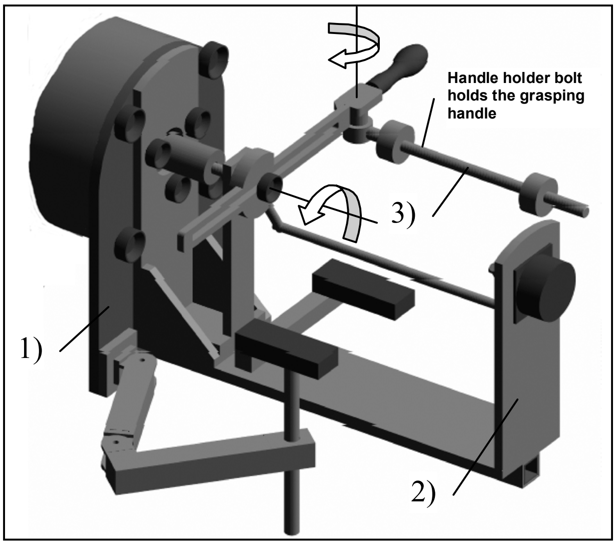

Figure 1: The handle of the DGAS can be adjusted in four degrees of freedom. Thus the rotational axis of the wrist joint can be adjusted to the BTE working simulator axis.

3) A grasping handle that incorporates five strain gage force sensors
4) A data acquisition and processing hard- and software that records the measurements of the forces, the angles and the subjects data.

The Handle

For the assessment of the grasping force generated by a neuroprosthesis, the system should be suitable of measuring the finger forces at different phalanxes and for different hand sizes. We decided to develop a very flexibly configurable grasping handle. It consisted of a hollow cylinder on which five sensor holder rings and several separator rings with different sizes could be assembled. The sensor holder rings could be rotated about the cylinder axis ϕ and therefore could be precisely placed under the targeted phalanxes. The handle was adjusted to the width of different hands, using separator rings with 4, 6, 8 and 10 mm thickness that were placed between the sensor holder rings. On each separator ring an angular scale was scribed. A groove in the hollow cylinder and press-fitted pins in each separator ring prevented the separator rings to rotate with respect to the hollow cylinder. Therefore the rotation angle of each sensor holder ring could be read off very easily.

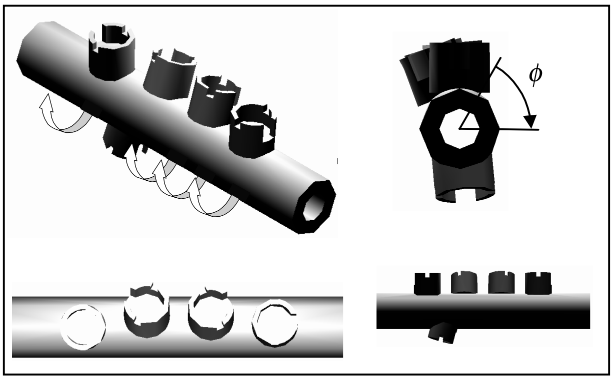

Figure 2: The scheme shows a typical assembly of the grasping handle using the sensor holder rings and the separator rings properly arranged on the hollow cylinder.

The grasping handle could also be used as a dynamometer without the grasping measurement device shown in Figure 1.

The Force Sensors

Extra small Entran strain gage load cells ELFM-B1-125 N were used for the grasping force measurement. The sensors measure pressure forces in the range of 0 N to 125 N. They have a diameter of 9.5 mm and a measuring surface of 5.29 mm^2. A metal housing for each sensor was designed to avoid damaging the very delicate load cells. The housing construction guaranteed that only orthogonal forces load the cell. Sheer forces falsify the result and could lead to damage of the load cell.

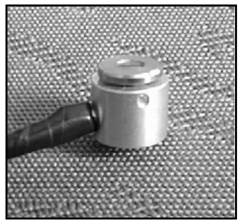

Figure 3: The small strain gage force sensors are packed in an aluminum housing from damage.

All five load cells were delivered with calibrated inline wired miniature amplifier modules. The miniature modules had an external null control screw and were temperature compensated. Each sensor/amplifier had a own calibration protocol, that guaranteed a non-linearity of 0.25 % FS (= Full Scale), a thermal sensitivity of 1 % per 50º C and a hystheresis of 0.25 % FS.

The Platform and the Grasping Measurement Device

The platform (see Figure 4) and the grasping measurement device were constructed in a way to fit a large number of different sized arms and hands. The platform supported the grasping measurement device and an adjustable (4 DOF) arm support was fixed on it.

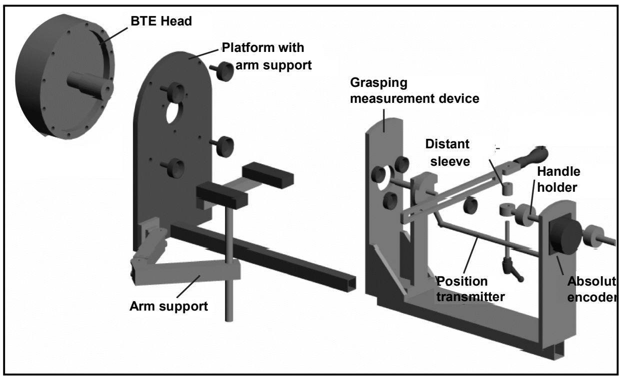

Figure 4: The parts of the DGAS are mounted to the BTE work simulator in the order from left to right.

The grasping measurement device shown in Figure 4 held the grasping handle in an adjustable, constant distance about the rotational axis of the BTE. Adjusting the orientation and height of the arm support and the distance and angle of the handle, the wrist rotation axis could be aligned with the BTE rotation axis.

The handle could also be fixed in vertical position, using a second handle holder bolt that was fixed perpendicular on the first handle holder. In this configuration dynamic force measurements for different radial/ulnar abduction angles could be done. The rotation angles were measured with an absolute encoder with a range of 360º and a resolution ± 0.25º.

The LabVIEW measurement software

The recording of the finger forces and the wrist angle were done with a software programmed in LabVIEW that provided the following functions:

- A software calibration function for the force sensors and the wrist angle encoder.
- Data storage in the Soleasy[1] data format.
- A real-time graphical display of the recorded data.
- A shuffle function for randomly setting different wrist angles.
- A spread-sheet like data base for the subjects' data and the device adjustment parameters.

We used a 12 bit DAQ-Card for the A/D conversion. The sampling frequency for all six recording channels was 500 Hz.

[1] Soleasy is a off-line data processing toolbox based on LabVIEW from Alea Solutions GmbH.

Positioning and Fixation of the Subject's Hand

The following procedure was applied to setup the DGAS to the individual subjects. First the grasping handle was adjusted. The able bodied subjects were asked to grasp a bar with 6 cm diameter to determine the natural finger spacing. The handle was assembled and the rotation angles of the sensor holder rings were adjusted. After putting the handle on the handle holder the subject was asked to grasp the handle. The arm support now was adjusted such that the wrist rotation axis (flexion/extension or ulnar/radial abduction axis) was aligned with the BTE rotation axis. To help the subjects to maintain constant finger positions, their finger tips or the chosen phalanxes were glued to the force sensors with thin adhesive double tape. The wrist angle was calibrated to neutral position (0º). We chose positive angle values for wrist extension/radial abduction and negative angle values for wrist flexion/ulnar abduction.

Preliminary Results

First preliminary measurement results were obtained from the dominant hand of 5 healthy subjects. After adapting the DGAS to the subjects' hand, they were asked to exert isometric full force on the handle for 2 seconds for different wrist angles. In these first trials only wrist extension/flexion was evaluated. The range of the measured wrist angles was from -80º to +60º using 20º steps. Every angle was measured five times randomly distributed. Between two trials a pause of minimal 20 s was introduced to avoid muscle fatigue.

Twenty samples of each trial were averaged about the maximum thumb force to determine the maximum finger forces of each finger. The vertical lines in Figure 5 indicate the location of maximum thumb force.

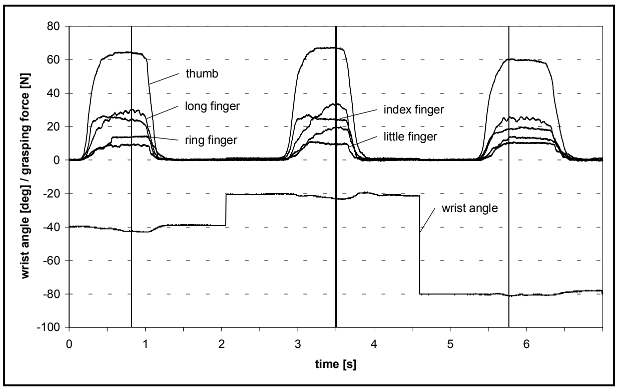

Figure 5: The figure shows the raw data of the measured finger forces and the wrist angle. The vertical lines are placed at maximum thumb force. The finger forces were evaluated at maximum thumb force.

For each subject the mean and the standard deviation of the five trials for each wrist angle was calculated. All forces were normalized for each wrist angle to the sum of the maximum index, long, ring, and little finger forces. Figure 6 shows the normalized results of one subject.

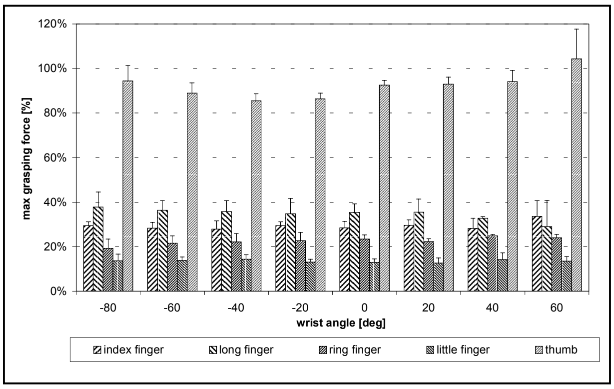

Figure 6: The average maximum finger forces of all 5 fingers from one subject are shown for different wrist angles. The forces are normalized to the sum of the maximum index, long, ring, and little finger forces.

Further the average normalized finger forces of all 5 subjects were calculated. They are listed in Table 1. The obtained results were compared with data from literature.

Our preliminary results							Hazelton et al. 1974 [5]	Amis 1987 [6]	Radhakrishan Nagarvindra 1993 [7]
wrist angle	-40°	-20°	0°	20°	40°	60°	**	*	*
index finger	34%	30%	29%	31%	30%	32%	25.4%	30%	31%
long finger	29%	30%	31%	29%	29%	29%	33.9%	30%	33%
ring finger	20%	22%	23%	22%	24%	22%	25.2%	22%	22%
little finger	17%	18%	17%	18%	17%	17%	15.2%	18%	14%

* left up to the subject

** experiments were done for five different angles; no significant difference for different angles were reported

Table 1: A comparison of our results of the percentage digital force distribution to the total finger force with studies done by Hatzelton et al. (1974), Amis (1987), and Radhakrishan, Nagaravindra (1993) showed similar results.

Discussion and Conclusion

The presented DGAS is capable of measuring the grasping force of each finger during dynamic wrist motion against torque. In our opinion this represents a novelty in dynamic grasping assessment.

The Entran ELFM-B1-125N strain gage sensors with in-line wired miniature amplifier modules measured the vertically on the sensor's head applied force in a range of 125 N with an accuracy of ±0.5 N. Additionally the system measured the wrist angle in its full range of motion of -85° to 75° for wrist flexion/extension and -15° to 45° for radial/ulnar abduction with an accuracy of ±0.25°.

Our first results obtained with 5 able bodied subjects showed that the DGAS can be adjusted to different hand sizes and provides consistent quantitative data about the grasping force distribution among the fingers for different wrist angles. Standard deviations of less than 10% (see Figure 6), except for extreme wrist angles, were a very good indication for consistent data, in spite of the small number of trials per wrist angle.

The thumb forces that opposed the finger forces, differed about ± 15% from the sum of the finger forces (see Figure 6). This indicated that the finger forces were not applied exactly orthogonal to the strain gage force sensors. The difference of the thumb force and the sum of the finger forces varied for different wrist angles. Thus, the error can not be eliminated for dynamic angle-force measurements by adjusting the sensor holder ring angles. Only 3-axis force sensors that to our knowledge are not available in such small size (like the Entran ELFM types), could improve our results.

A comparison of the preliminary obtained data with studies done by Hatzelton et al. (1974), Amis (1987), and Radhakrishan and Nagaravindra (1993) [5-7] indicated that the DGAS is capable of measuring consistent grasping forces for different subjects.

The capability to measure the grasping forces at different phalanxes of the human hand can be very useful for the evaluation of the optimal electrode positions of grasping neuroprostheses using surface stimulation. The DGAS allows to perform such an evaluation for different wrist angles. It will be a future task to use the DGAS for that kind of application.

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