Instrumented handles for an arm rehabilitation robot

Marco Guidali[1,2], Roman Erne[1,2], Olivier Lambercy[3], Roger Gassert[3] and Robert Riener[1,2]

[1]Sensory-Motor Systems Lab (SMS), Institute of Robotics and Intelligent Systems (IRIS), ETH Zurich, Switzerland
[2]Medical Faculty, University Hospital Balgrist, University of Zurich, Switzerland
[3]Rehabilitation Engineering Lab (RELab), ETH Zurich, Switzerland
Contact: marco.guidali@mavt.ethz.ch

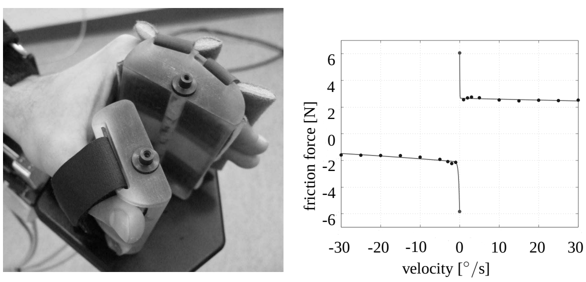
Introduction

After stroke, patients often receive arm therapy to restore motor function. In rehabilitation, robotic devices such as ARMin can be used to assist the patient in training arm and hand function [1]. Low friction, negligible backlash and backdrivability are important requirements for such devices [2]. Static friction in the joints can hinder weak patient from initiating a movement, especially in the case of hand and finger function, where relatively small forces can be produced. As self-initiation is considered to be essential in motor-learning [3], we developed a sensor concept for the hand module of ARMin to detect the patient's intention and reduce the amount of initiating force needed to open and close the hand.

Materials and Methods

Hand module of ARMin

ARMin is a rehabilitation robot developed at ETH Zurich in collaboration with the University Hospital Balgrist. The newest version consists of seven actuated degrees of freedom, including a hand module, which supports opening and closing of the hand (Fig. 1(a)). The hand module has one actuated degree of freedom to move two mechanically coupled handles, where the four fingers are fixed by textile straps to one handle and the thumb to the other. To use the same handles for the left and right hand, they can be detached, flipped around and attached to the other shaft.



(a) (b)

Figure 1: Hand module of ARMin a) and the measured friction profile b)

Friction of the hand module was measured with external force sensors and the motor current (Fig. 1(b)). The determined static friction was ± 6.0 N, which is relatively high with respect to typical interaction forces at the hand and fingers.

Instrumented hand module

The hand module of ARMin is equipped with a position encoder. If a subject can overcome static friction of the device, movement intention can be detected and assisted with an impedance controller. To detect the intention already before the applied force exceeds static friction, single axis force sensors were integrated into the handles. The finger and thumb handles were cut in half to place the sensors inside the handles. Preloaded with springs, this concept enables a bidirectional measurement of forces and avoids the difficult integration of sensors into the textile straps. Influence of lateral forces on the measurement was minimized with cylindrical pins and bushings to guide the movement. On the finger handle, three low-cost piezo-resistive force sensors (CentoNewton, EPFL Lausanne, Switzerland) were arranged in a triangular manner, so that the center of pressure is kinematically determined. Each sensor can measure force in a range of $0 - 40$ N with a resolution of ≤ 0.05 N.

For the thumb handle a simplified version with only one sensor was used, because translational movement of the thumb is restricted by the shape of the handle. The sensor is placed right below the thumb if the right hand is used. If the handle is used on the left hand, a rotational guidance in the center of the handle transmits the force to the force sensor.

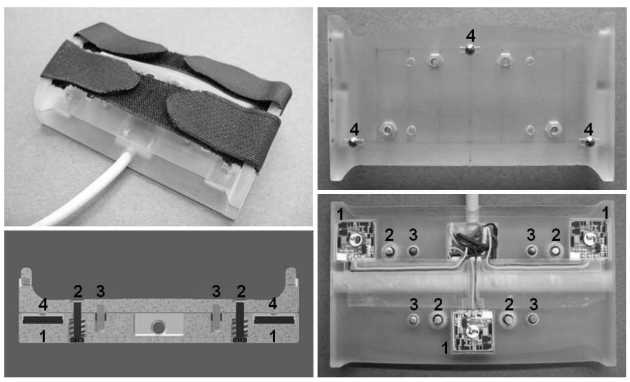


Figure 2: Detailed view of the finger handle, 1: force sensors, 2: springs with screws for sensor preload, 3: cylindrical pins with bushings for linear guidance, 4: balls for force transmission

Force control

With the designed handles, many approaches to assist the patient can be implemented. To evaluate the quality of the force signal for control purposes, a force controller was implemented. By setting the desired force to zero, the controller tries to minimize the interaction force between the human hand and the handles and follows the induced movement smoothly.

This would be a suitable assistive control strategy for weak patients because the applied force can be amplified to drive the motor and, thus, would give the patient full freedom over opening and closing the hand.

The assistive motor torque τ_m is given by,

$$\tau_m = K_F \cdot (0 - F_{tot}) \cdot l \cdot g \quad (1)$$

where K_F denotes the force gain, F_{tot} the total force applied by the fingers and the thumb, g the gear ratio and l the lever between handle shaft and motor axis.

Results

Instrumented hand module

Accuracy of the developed sensor concept was evaluated with a dynamometer (AFG 100, Mecmesin, UK) to measure compressive forces. A test setup with constant load on the textile straps was used to measure tensile forces. Also the influence of lateral forces on the measurement was determined. In all cases a force of 10 N was applied at different contact points on the handle surface or on the straps.

Table 1: Accuracy of instrumented handles

Force type	Finger handle mean error [%](SD)	Thumb handle mean error [%](SD)
Compression	2.6 (3.1)	0.2 (0.4)
Tension	3.7 (0.5)	2.5 (0.9)
Lateral	3.3 (0.4)	1.3 (0.2)

In a second experiment each handle was attached to a commercial 6-DOF load cell (ATI Mini40, SI-80-4), which allows to measure forces and torques with a resolution of 0.04 N and 0.5 mNm, respectively. Seven healthy subjects tried to open and close the hand while the handles were blocked (Fig. 3). The mean relative error between the multi-axis sensor and our finger and thumb handle was 2.5 % and 2.0 %, respectively.

Force control

The force controller was evaluated with five healthy subjects. Each subject had to open and close the hand five times without robotic support and five times with different support from the force controller (K_F = 1,2,3). Without force support the mean force applied by the subjects to open and close the handle was -2.8 N and 4.8 N, respectively. As expected, the force required to move the handle decreased with increasing force gain (Table 2) to a minimum of -0.68 N and 0.96 N for $K_F = 3$.

Discussion

With the developed force measurement concept for fingers and thumb, new patient-cooperative control strategies can be implemented for the hand module of ARMin. The implemented force controller allows to adjust the amount of force needed to open and close the hand individually for each subject. However, the controller was only tested with healthy subjects and in a next step clinical tests with stroke patients need to be conducted. Furthermore, the influence of movement of the other six ARMin joints on the force measurement has to be investigated.

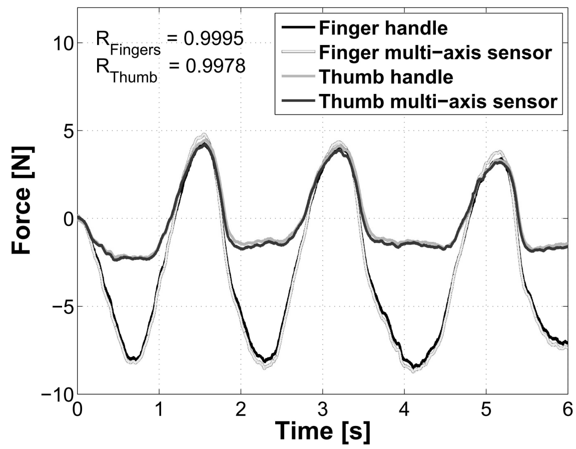


Figure 3: Comparison of the instrumented handles with a commercial 6-DOF load cell, while a healthy subjects is trying to open and close the hand.

Table 2: Forces needed to move the hand module with different gains for the force control support

Force	$K_F = 0$	$K_F = 1$	$K_F = 2$	$K_F = 3$
Mean force to open	-2.89 N	-1.35 N	-1.02 N	-0.68 N
Mean force to close	4.72 N	2.18 N	1.33 N	0.96 N

Conclusion

The presented instrumented hand module allows to measure thumb and finger forces very accurately with low-cost sensors. Based on the force information, static friction of the device can be compensated and intention forces amplified and, thus, could make it possible for most patients to actively perform hand training with the ARMin handles during post-stroke therapy.

References

[1] NEF, T. ; GUIDALI, M. ; RIENER, R.: ARMin III - arm therapy exoskeleton with an ergonomic shoulder actuation. In: *Applied Bionics and Biomechanics* 6 (2009), Nr. 2, S. 127–142

[2] KREBS, HI: Rehabilitation robotics: pilot trial of a spatial extension for MIT-Manus. In: *J Neuroeng Rehabilitation* 1 (2004), Nr. 5, S. 1:5

[3] PEREZ, MA ; LUNGHOLT, BK ; NYBORG, K ; NIELSEN, JB: Motor skill training induces changes in the excitability of the leg cortical area in healthy humans. In: *Exp Brain Res* 159 (2004), Nr. 22, S. 197–205