THE NTNU REVOLUTE WRIST DEVICE (NRWD): A KINEMATICALLY OPITMIZED EXTERNALLY POWERED WRIST PROSTHESIS

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INTRODUCTION

Transradial amputation implies the loss of the wrist and thus the loss of the ability to do flexion/extension and radioulnar deviation as well as the forearm's ability to rotate the wrist (prosupination). Prosupination is offered by some prostheses, but many users choose not to use a powered wrist because the benefits are literally outweighed by its weight, poor cosmesis and the complexity of controlling multiple degrees of freedom. This is also why a wrist with more than one motorized function is considered by many to be an unviable concept.

This paper reports a study that aims at producing a lightweight, single-DoF, externally powered wrist whose kinematic properties are optimized to match those of a healty wrist in conjunction with certain Activities of Daily Living (ADL). The rationale for this is the assumption that reducing the need for compensatory movements whilst keeping the weight and control complexity unchanged will improve user acceptance and utilisation of the device. The wrist provides for digital communication and coordinated motion.

OPTIMAL KINEMATICS

Data Acquisition and Calculations

Eight healthy subjects were asked to perform 15 different ADL while their forearm and hand movements were measured with a MotionStar electromagnetic tracker (Ascension Technology Corp., Burlington, VT, USA). Subsequently a one-degree-of-freedom kinematic model was fitted to the entire data set as well as to the data subsets for each activity, age group and sex. The kinematic model comprised an axis of rotation and a rotational offset that allowed the hand to be statically tilted perpendicularly to the axis of rotation [1]. Orientation statistics was employed in order to decouple the results from the choice of reference coordinate frames [2].

Results

The grand axis of rotation (based on all the data) was found to go through the wrist from a dorsal-lateral position proximally to a ventral-medial (palmar) position distally, forming an angle of 10.7° with the forearm and 6.9° with the sagittal plane. Furthermore the axis was displaced 18.9° with respect to the 3rd metacarpal and 13.2° with respect to the palmar plane of the hand. Figure 1 shows two wrist postures corresponding to this grand axis of rotation; note the presence of a wrist extension (i.e. a rotational offset) throughout the wrist's workspace.

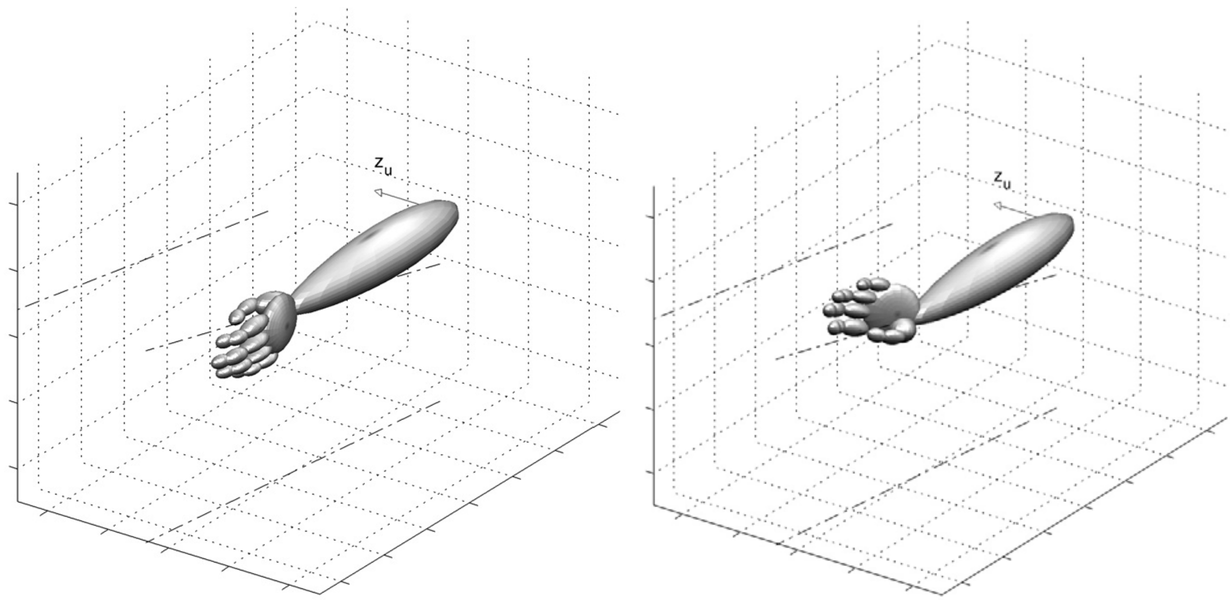

Figure 1 Grand axis of rotation. The axis is indicated with a dash-dotted line, which is projected onto a horisontal and a vertical plane in order to help in the three-dimensional interpretation. The arrow labelled Z_u marks the medial direction. The left figure shows the wrist in a somewhat "neutral" posture, while to the right the wrist is rotated 180º about the grand axis.

There were only small differences in the dominating axes of rotation for various groups of subjects, but significant deviations were found between the different ADL [1].

THE PROSTHESIS

The NTNU Revolute Wrist Device is an experimental design adapted to research on prosthesis kinematics, coordinated joint control and digital communication. The following sections outline the features of the first version of the wrist, referred to as NRWD-1.

Kinematics

Obliquity of the axis of rotation with respect to the forearm causes the wrist's cross-section to be elliptic, cf. Figure **2**. This is desirable because a healthy human wrist is in fact elliptic rather than circular. While the grand axis of rotation identified implies an almost circular design, the axis for individual ADL with the largest component in the dorsal-ventral direction yielded a wrist aspect ratio of more than 3:1.

The orientation of the axis of rotation and the static rotational offset between forearm and hand heavily influence the cosmetic appearance of the device, for example some male users consider a pemanent wrist extension to be feminine. Since the different ADL also suggested quite different kinematics it was decided to make the rotational offset adjustable, with the grand kinematic parameters as the preferred configuration.

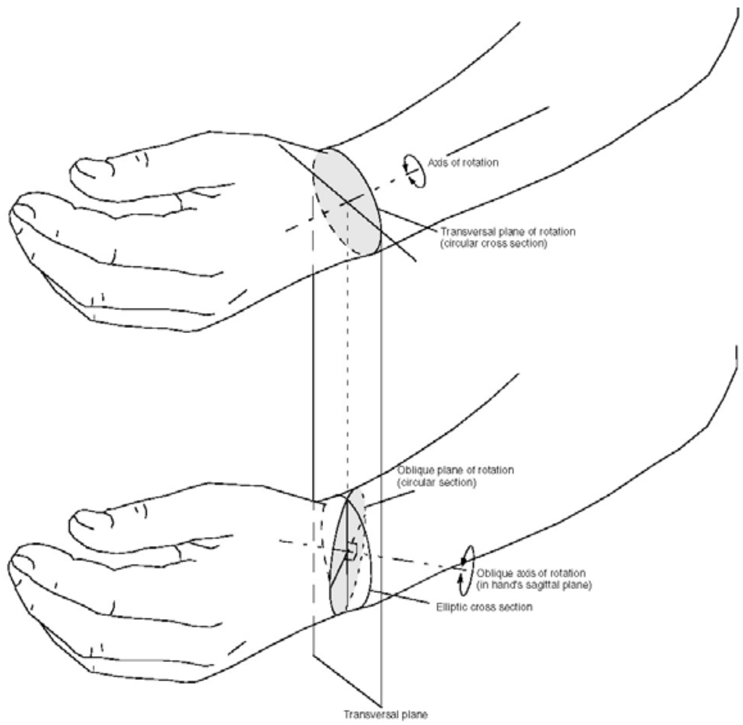

Figure 2 An oblique axis of rotation gives a more human-like elliptic cross-section.

Interfaces

Being an experimental device, the NRWD-1 should be able to operate with a multitude of other prosthetic components. Therefore it will not have a definite mechanical interface but rather be adapted to each situation.

The power interface tolerates supply voltages in the range 6-12 V, which covers most comercially relevant voltages. The device includes a microcontroller with two proximal and two distal communication lines configurable as a CAN or I^2C bus or as dual analog inputs and outputs, respectively, for compatibility with commercial terminal devices as well as other experimental systems. Digital comunication is believed to dominate the prostheses of the future, as it is nearly a prerequisite for more advanced coordinated multi-joint movement and it easily gives room for future growth in the amount of data transferred between different parts of a prosthesis (i.e. terminal device, wrist, elbow and control input electronics). The initial prototype cirquit (Figure 3) employs DIP-switches for switching between the communication modes, but a future version will be based on solid-state components only. Furthermore, future versions will most likely be limited to a single data bus standard, depending on the success and direction of relevant developments and standardisation activities [3]. Provisions are made for the NRWD-1 to read digital commands proximally and simulate analog EMG signals distally so that traditional terminal devices can be combined with novel arm components, using the NRWD-1 as a “glue component”.

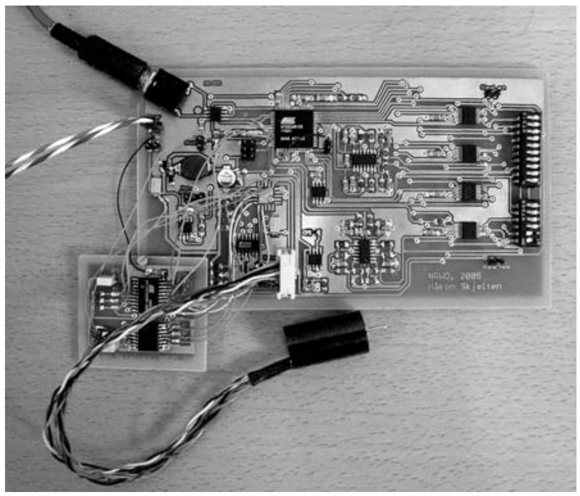

Figure 3 First prototype of the NRWD-1 control electronics. Below the large cirquit board is the minute but powerful brushless motor that drives the wrist.

Modes of Operation

The control software is modular, transparent to the communication mode. The control modes available include on/off, proportional torque, velocity or position and mechanical impedance. Electromechanical properties are comparable to those of commercial devices. Emphasis is put on creating a fast dynamic response to allow continuous active use of the wrist as opposed to using it occationally for re-orienting the hand.

DISCUSSION

The NRWD-1 is a novel experimental wrist prosthesis is adapted to research on prosthesis kinematics, coordinated joint control and digital communication. A number of challenges are yet to be met, including miniaturisation of the control electronics to obtain a single, self-contained unit. An expected outcome is to document the benefits, if any, of a kinematically optimised design in the presence of traditional as well as advanced and novel control schemes.

ACKNOWLEDGEMENTS

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