Robotics: Science and Systems 2009, Seattle (WA), USA
Workshop Understanding the Human Hand for Advancing Robotic Manipulation
Organizers: Ravi Balasubranian, Yoki Matsuoka

Human hand kinematics based on MRI imaging

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Anthropomorphic robot hands have come to a technical level where understanding exact human hand kinematics becomes relevant, e.g. the hand/arm system that is presently being developed at DLR (Fig. 2, Grebenstein and van der Smagt, 2008). Human hand kinematics have been investigated through cadaver hands (e.g. Hollister et al., 1992 and 1995) and optical motion tracking of surface markers (e.g. Cerveri et al., 2005). A problem with the former is that tissue properties might be altered due to tissue necrosis. With the latter, the motion of the skin relative to the bones leads to so called soft tissue artifacts (STA) that negatively influence the quality of the results (Ryu et al., 2006). To allow *in vivo* measurements and to avoid STA, we recorded finger postures by magnetic resonance imaging (MRI, Table 1 and Fig. 2). We used a method similar to the one described by Miyata et al. (2005), but with a much larger number of hand postures, resulting in a model with multi-degree-of-freedom (multi-DoF) joints.

MRI images of the hand were taken in fifty different static postures (Fig. 3). The postures were chosen so that for each joint, the extreme poses as well as intermediate ones are included; furthermore, the opposition movement between thumb and fingers is covered extensively. One hand posture is defined as reference. The pose of each bone in the other postures is described by a rotation and translation from the reference posture (Fig. 4). The first step for determining the pose is the segmentation of each MRI image, i.e. identification of the point set of each bone. Next, a statistical method by Hillenbrand (2008) is used to find the rotation and translation parameters that are necessary to match the point sets of the same bone. From this, the relative poses with respect to the neighbor bone are calculated (Fig. 5).

Seven joint models with varying degrees of freedom and intersecting and non-intersecting axes of rotation are defined to be valid (Fig. 6): A joint with one rotation axis (1DoF), a joint with one DoF but two coupled rotation axes (1DoF_2c), a joint with two rotation axes (2DoF), a joint with two rotation axes that are orthogonal to each other (2DoF_o), a joint with two non-intersecting rotation axes (2DoF_ni) and two joints with three mutually orthogonal axes that are oriented with the bone geometry (3DoF and 3DoF_ni).

For each joint, the parameters of the joint models are adapted numerically to fit the measured bone poses. This is done by numerically minimizing the orientational and the translational discrepancy between the modeled and the measured bone poses, using the *fminsearch* function within *Matlab*. The orientational discrepancy is defined as the rotation angle of a rotation that is necessary to match the orientation of the modeled and the measured bone pose (Fig. 7). The translational discrepancy is defined as the mean distance of the bone surface point in the modeled and the measured pose (Fig. 8).

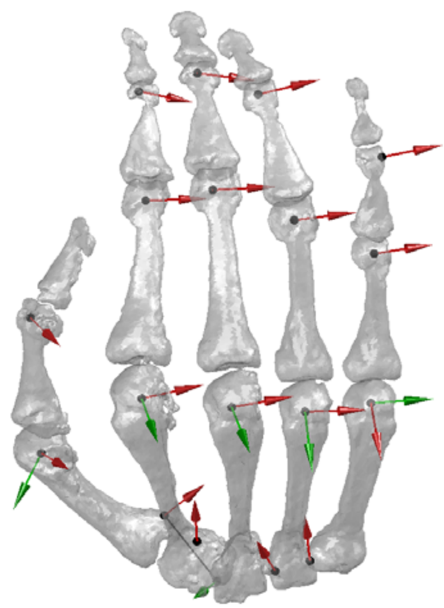

Fig. 9 DLR's kinematic hand model with mean errors smaller than 6° and 3 mm. With 2-DoF joints, the first joint axis is drawn as a red arrow and the second one as a green arrow.

By setting a limit for the discrepancy values, each joint was assigned one of the seven joint models. For example, a limit of 6 degrees mean rotational discrepancy and 3 mm mean displacement leads to a kinematic hand model with 21 DoF in the fingers plus 3 DoF in the palm, shown in Fig. 9. In this model, the following joint models are used: A two-DoF joint with non-intersecting axes (2DoF_ni) for the thumb saddle joint, two-DoF joints with orthogonal, intersecting axes (2DoF_o) for the metacarpophalangeal joints and one-DoF joints (1DoF) for the interphalangeal and the intermetacarpal joints.

Virtual grasping experiments will be conducted with this hand model to see if it has advantages over the simplified kinematics that were used so far for the design of the robotic hand/arm system.

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MRI scanner:	Philips Achieva 1.5 T
MRI coil:	Philips Sense 8-channel
sequence:	balanced FFE
resolution:	$(0.67\ mm)^3$ physically
	$(0.38\ mm)^3$ interpolated
time per shot:	approx. 4 min.

Table 1 Parameters of the MRI measurements

Fig. 1 Design prototype of DLR's new robotic hand/arm system.

Fig. 2 An MRI scanner unit and a hand inside an MRI sensor coil.

Fig. 3 Hand postures.

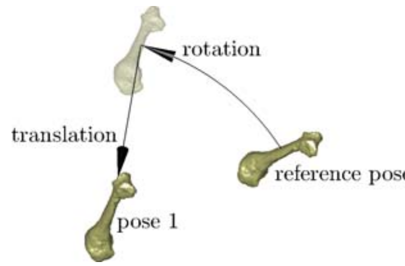

Fig. 4 Definition of a bone pose by a rotation and a translation.

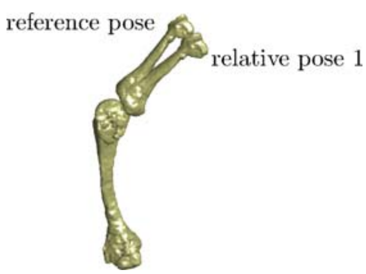

Fig. 5 Relative poses of the a joint in two hand postures.

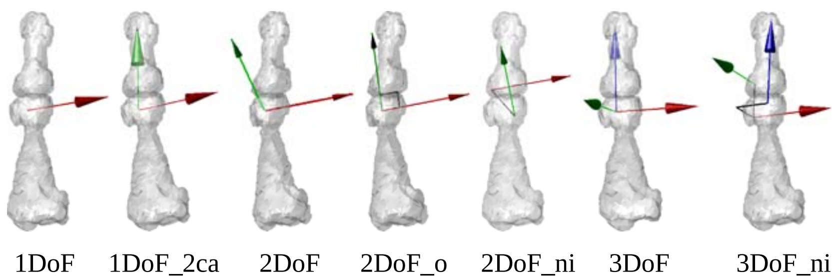

Fig. 6 Joint types.

Fig. 7 Orientational discrepancy between two poses.

Fig. 8 Translational discrepancy is defined as the mean distance between surface points. Here five example points are shown.

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