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Predicting Carpal Bone Kinematics using an Expanded Digital Database of Wrist Bone Anatomy and Carpal Kinematics

Bardiya Akhbari, Douglas C. Moore, David H. Laidlaw, Arnold-Peter C. Weiss
Edward Akelman, Scott W. Wolfe, Joseph J. Crisco

For additional data and periodic updates, check https://simtk.org/projects/carpal-database

Corresponding Author:

Joseph J. Crisco, Ph.D.
Bioengineering Laboratory
Department of Orthopedics
The Warren Alpert Medical School of Brown University and Rhode Island Hospital
1 Hoppin Street, CORO West, Suite 404
Providence, RI 02903
(401) 444-4231/ (fax) (401) 444-4418
Email: joseph_crisco@brown.edu

Table of Contents

Short-hand Folder Structure:

StudyGroup

AgeGroup

SeriesNames.ini (configuration file linking the number folder to an orientation)

GenderGroup

StudyID

***##Side*([R/L]) (a folder one for each series captured)**

*StudyID*_Motion*##side*.dat (a 60x3 array, transforms for each bone from neutral to this series position.

***Side*([Right/Left])IV**

IV.files (points and connections files – triangular meshes for each bone [15 bones])

***Side*([Right/Left])Info**

Inertia Coordinate System.dat

Radius Coordinate System.dat

Bone Volumes.dat

*StudyID*_demographic.txt (text file with [gender([F/M]) age] written inside)

Overview

The open-source database is organized by study group and subject ID, which is a randomly generated five-digit number to satisfy HIPAA requirements. Each subject has brief demographic descriptors, including gender, age (young < 45 yrs.), and wrist side. In addition, each subject's folder contains the carpal bones' computed volume within the outer bony cortical shell and 3D models of the carpal bones, radius, and ulna in their neutral pose within the CT scan coordinate system. Three dimensional models are provided in an IV format (i.e., a scene graph file of vertices coordinates and connections). The RCS, the inertial coordinate system of carpal bones in the CT space, and the kinematic transformations of bones from their neutral pose to the target pose in the CT space ($Bone_{mRT}$ and $Radius_{mRT}$) are also available in the subject directory.

Database File Structure and Contents

To satisfy HIPAA confidentiality requirements, the database is organized by subject, with data from each subject contained in a separate zip file labeled with a randomly generated four and five-digit number (e.g., 14819). Data for individual subjects are grouped by scanning protocol (incremental orthogonal [Orthog_Tasks], combined motion [CombinedMotion_Tasks], carpometacarpal study [CMC_Tasks], and functional tasks study [Functional_Tasks]), then age (young vs. old), and then gender (male vs. female).

The dataset for each subject includes brief demographic descriptors (age and gender), clinical exam results (range of motion), surface models, volumes, centroid coordinates, inertia magnitudes and inertial principal axes for each bone; a series of kinematic transforms that locate each of the bones for each subsequent wrist position with respect to its neutral position; and for convenience a transform to position all of the bones in a radius-based coordinate system. All data is provided in ASCII tab-delimited format, with file names, format, and folder structure described below. In all cases where bone-specific data is listed sequentially (i.e. volume, inertial or kinematic data), it is presented in the following order: radius, ulna, scaphoid, lunate, triquetrum, pisiform, trapezoid, trapezium, capitate, hamate, metacarpal 1, metacarpal 2, metacarpal 3, metacarpal 4, and metacarpal 5.

A single folder titled with the randomly generated five-digit identification number contains all the files for a given subject. Within this folder, the demographic data is included in a single text file (e.g., 14819_demographic.txt), which includes the subject's age and gender (1x2 array). (when ages for subjects were unavailable they are listed as "99"). If existed, the range of motion and grip strength are presented in two separate text files, one for each wrist (e.g. 14819_ClinicalExam_L.txt and 14819_ClinicalExam_R.txt). In both cases, the range of motion data is presented in a 5x1

array, in the following sequence: flexion (deg), extension (deg), radial deviation (deg), ulnar deviation (deg), and the grip strength.

SubjectID Info Folder

The subfolders "RightInfo" and "LeftInfo" contain the volume files, inertia files and coordinate system transform for each bone in the right and left wrists, respectively. For example, the file "14819_volume_R.dat" in the RightInfo folder contains the volumes (mm^3) of all the bones in the right wrist of subject 14819, and the file "14819_inertia_L.dat" in the LeftInfo folder contains the inertia data for all the bones in the left wrist of subject 14819. The volume data is contained in a simple 15x1 array, while the inertia data is contained in a 75x3 array generated by concatenating the 5x3 arrays containing the data from each of the individual bones, which included the centroid coordinates (a 1x3 vector), the magnitudes of the principal inertia axes (a 1x3 vector), and unit vectors for the principal inertial axes in column format (3x3 matrix). The coordinate system transform is a 4x3 array, which is provided as a 1x3 translation matrix concatenated to a 3x3 rotation matrix. The naming of the coordinate system transforms follows the convention: “14819_RCS_L.dat” (for the left wrist transform).

SubjectID IV Folder

The subfolders "RightIV" and "LeftIV" contain the OpenInventor/ASCII surface models. Each model is included as a separate file identified with a three-character abbreviation: rad = raduis, uln = ulna, sca = scaphoid, lun = lunate, trq = triquetrum, pis = pisiform, tpd = trapezoid, tpm = trapezium, cap = capitate, ham = hamate, and mc1, mc2, mc3, mc4, mc5 for metacarpals 1 through 5, respectively.

Motion Folders

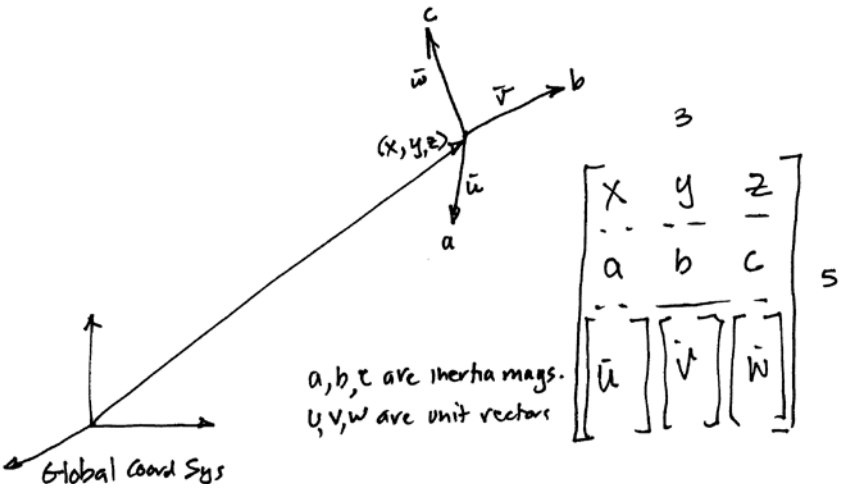
The remaining subfolders contain the rigid body transforms for positioning the forearm and carpal bones with respect to the reference neutral position (transforms are not reliable for metacarpal bone motion as their full image was not acquired). Each of these folders contains a single file, tagged with a three-character alphanumeric identifier (e.g. 04L) which specifies the wrist (L=left, R=right) and targeted scan position. There is a SeriesNames.ini file in each group's folder that demonstrates the configuration file linking the number folder to an orientation. For the incremental orthogonal protocol, positions 01 through 07 correspond to "targeted wrist positions" of 30˚ and 60˚ of flexion, 30˚ and 60˚ of extension, 20˚ and 40˚ of ulnar deviation, and 20˚ of radial deviation, respectively. For the combined motion protocol, positions 01 through 08 correspond to targeted wrist positions of 40˚ of flexion, 40˚ of extension, 10˚ of radial deviation, 30˚ of ulnar deviation, and combined motions of 40˚ flexion and 30˚ ulnar deviation, 40˚ extension and 30˚ ulnar deviation, 40˚ extension, and 10˚ radial deviation, and 40˚ flexion and 10˚ radial deviation, respectively. For the functional tasks, subjects were studied in extreme wrist flexion, extreme wrist extension, and five positions along the path of dart-thrower's motion. For the CMC tasks, subjects' thumb was moving in various poses (neutral pose, adduction, abduction, flexion, extension, jar twist, jar grasp, and key pinch), while the wrist motion was unconstrained. Each file contains a concatenated series of rotation matrices (R_i, [3x3]) and translation vectors (T_i, [1x3]) in the bone order described previously (radius, ulna, scaphoid, lunate… see above).

For further processing, each carpal bone motion can be calculated in the radial coordinate system with respect to the neutral pose (Eq. 1):

$$Bone_{MotionInRadCS} = RCS^{T}_{4x4} \times Radius_{mRT}{}^{T} \times Bone_{mRT} \times RCS_{4x4} \qquad \text{(Eq. 1)}$$

, where *Bone* refers to a specific carpal bone, $Bone_{MotionInRadCS}$ is a 4×4 kinematics transformation in the radial coordinate system, RCS_{4x4} is a 4×4 homogeneous matrix defining the radial coordinate system position and orientation within the CT space, $Radius_{mRT}{}^{T}$ is a transposed of a 4×4 kinematic transform of a radius neutral position to target pose, $RCS^{T}{}_{4x4}$ is the transposed of RCS_{4x4}, and $Bone_{mRT}$ is a 4×4 kinematic transform of a bone from neutral to target pose.

Inertia Arrays Description



Coordinate System Transformation