SBIR Phase I Progress Report

Grant Number: 1R43OH009681-01

Grant Title: Scalable and Deformable 3D Hand Model for use with Computer Aided Engineering Designs

Begin Date of SBIR Phase I: September 1, 2009

End Date of SBIR Phase I: August 31, 2010

Senior/Key Personnel

David Wagner, Ph.D., Project Manager, 9/01/09 – 1/01/10, 185 hours

Metin Ozen, Ph.D., President, Ozen Engineering, 1/01/10 – 8/31/10, 18 hours

Matt Camilleri, Ph.D., Post-Doctoral Fellow, 9/01/09 – 8/31/10, 600 hours

David Rempel. M.D., Professor, 9/01/09 – 8/31/10, 24 hours

Xudong Zhang, Ph.D., Associate Professor, 9/01/09 – 8/31/10, 10 hours

Section 1 of the Final Progress Report

Significant (Key) Findings:

A kinematic model of the human hand is developed that determines how the hand bones move with respect to each other. The kinematic model, when integrated into the CAD model, allows the modeled hand to be posed in real configurations. The ability to pose the modeled hand realistically is necessary to understand how the hand would interact with a proposed tool or interface.

Translation of Findings:

The kinematic model provides the framework for integrating other models (kinetic and predictive). The fully integrated model (Phase II) will allow for optimizing the design of tools and interfaces to reduce risk and increase access and functionality.

Outcomes/Impact:

Consider an engineer/designer working with a piece of 3D geometry that represents a new hand held device. With the proposed integrated suite of models, that engineer/designer may call up different sized animated hands in the same CAD environment as the new device and accurately place the device within the hand based on hand contact points and visual requirements. The software program will allow the engineer/designer to visualize the feasible design space (e.g. the work volume of the thumb) related to trigger/switch positions and grasp contacts of the device. An iterative process, wholly with use of a computer, can thus be used to generate an optimized design that decreases risk from awkward postures and increases access and functionality through optimized geometry of the device.

Section 2 of the Final Progress Report – Scientific Report

Motivation and Specific Aims:

The ability to accurately predict how a specific hand would interact with a novel tool or manual interface would allow engineers and designers to optimize tool and interface designs which reduce risk and increase access and functionality. This ability can be realized by integrating three specific models; 1) a kinematic model (how the hand bones move with respect to each other, and the unloaded topography of the hand), 2) a kinetic model (how the skin deforms as an object is grasped or manipulated), and 3) a predictive model (the grasping or manipulative strategies based on the topography of the tool/interface).

The purpose of this Phase I project was to develop the kinematic model and provide a framework with which to 1) develop the other two models and 2) integrate all three models. The project was divided into three specific aims:

Aim 1. Kinematic (Skeletal) Model: Joint center estimation techniques were used to define finger and thumb joint centers of rotation and functional phalange lengths from sensors attached to the hand. The finger joint centers of rotation were integrated into an existing solid geometry hand model.

Aim 2. Regression (Estimation) Model: The minimum sufficient hand dimension variables for defining population percentile scaling relationships (for phalange lengths and surface landmarks) was determined. Detailed hand-scaling libraries were summarized with 25th, 50th and 75th %tile hands. This model may be used to estimate the hand geometry of any sub-population.

Aim 3. CAD Model: A CAD implementation for the scaling relationships developed in Aim 2 that includes phalange lengths, joint kinematics, and surface geometry was developed. This model provides the framework for integrating the future kinetic (skin deformation) and predictive (grasping/manipulation strategy) models.

Results:

To generate inclusive models, research participants were targeted based on hand width, hand breadth, gender, and ethnicity. Table 1 presents the target versus actual populations.

	Target			Actual		
	Females	Males	Total	Females	Males	Total
Ethnic Category						
Hispanic/Latino	2	2	4	1	1	2
Not Hispanic or Latino	11	11	22	12	12	24
Ethnic Category: Total of All Subjects	13	13	26	13	13	26
Racial Categories						
American Indian/Alaska Native	0	0	0	0	0	0
Asian	1	1	2	2	3	5
Native Hawaiian or Other Pacific Islander	0	0	0	0	0	0
Black or African American	2	2	4	1	0	1
White	10	10	20	10	10	20
Racial Categories: Total of All Subjects	13	13	26	13	13	26

Table 1: Target versus Actual Enrollment Demographics.

Aim 1: Kinematic (Skeletal) Model:

Progress toward achievement

The kinematic model was defined by joint centers, which were computed using sensor data collected during finger motion (e.g. flexion and extension, Figure 1). Multiple trials of finger motion were performed and each trial was used to compute joint centers. The distance between joint centers defined the phalange (bone) lengths, and the variability in length, between these trials and within each subject, was comparable to the variability between subjects (Figure 2). Connecting adjacent joint centers (as well as the finger-tips), provides a graphical representation of the kinematic model (Figure 3).

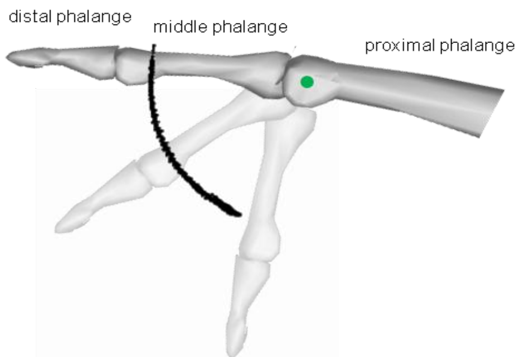

Figure 1: Example Sensor Position During Finger Motion. The trajectory of the sensor (small black markers attached to skin) defines the center of rotation (large green marker).

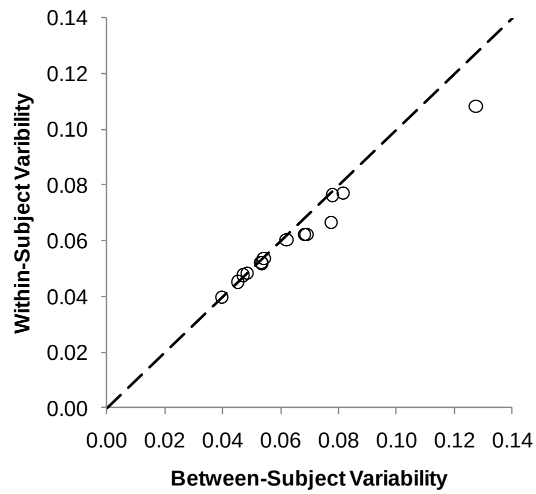

Figure 2: Bone Length Variability.

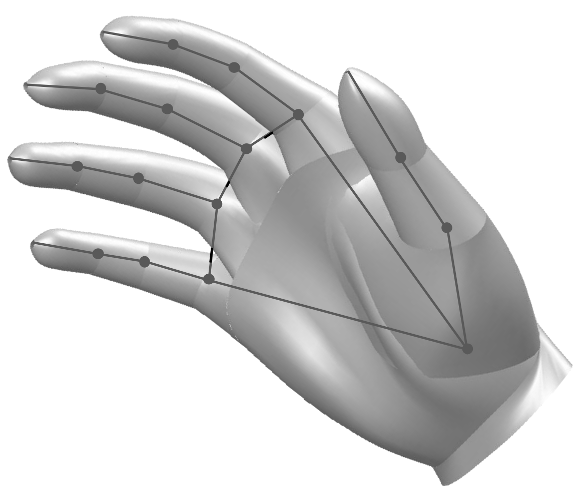

Figure 3: Computed Joint Centers within a CAD representation of the hand. Joint centers are represented as filled markers.

Changes to specific aim 1

A goal of this aim was to exploit a data set collected from a previous study (Rogers et. al., 2008) so as to increase the effective *n* of the kinematic model. This was to be done by validating that the joint centers computed using palmar surface landmarks from 4 static postures were comparable to the joint centers computed using dorsal surface sensor data collected during joint motion. Because the joint centers between the two methods were not comparable, we were not able to exploit the previous dataset. The assumption for both computational methods is that the landmarks/sensors are fixed with respect to the underlying bones. Whereas the dorsal surface sensors were relatively fixed to the underlying bones, the palmar landmarks, near the junction of adjacent bones, could not be associated with a distinct bone. Additionally, because of the variability of joint angles between the current and previous data sets (Figure 4), the confidence in estimated joint centers from the previous data set could not be established.

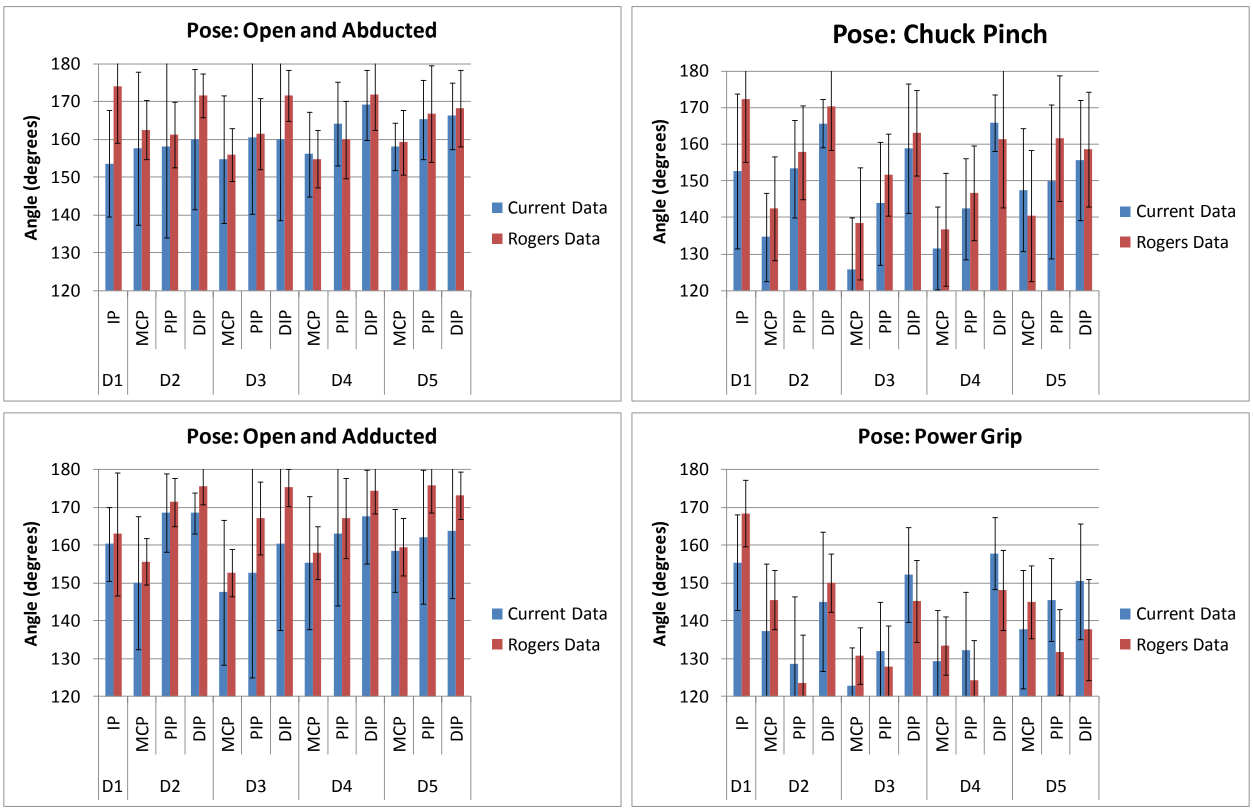

Figure 4: Comparison of Interphalangeal Joint Angles Between the Current and Previous (Rogers et. al., 2008) data sets. The data sets demonstrate similar trends between poses. Within a pose, the means between data sets vary up to 15°.

Importance of the findings

The kinematic model, when integrated into the CAD model, allows the modeled hand to be posed in real configurations. The ability to pose the modeled hand realistically is necessary to understand how the hand would interact with a proposed tool or interface.

Aim 2: *Regression (Estimation) model*

Progress toward achievement

A library of statistical relationships that relates hand anthropometry and gender to individual underlying skeletal structure and surface landmarks was generated. Main effects (e.g. hand length) and two-way interaction effects (e.g. hand length X hand width) were allowed in a forward step-wise model building process (p<0.01 to enter and p<0.05 to leave). Example scaling parameters (Table 2), the relationship between computed and predicted phalange lengths (Figure 5), and the CAD model integrating these parameters (Figure 6) are presented.

			Regression Coefficient										
Digit	**Phalange**	**R^2**	β_0 (Intercept)		β_1			β_2			β_3		
			value	*p*	Effect	value	*p*	Effect	value	*p*	Effect	value	*p*
1 (thumb)	Proximal	0.66	1.308	0.002	HW*D2P	0.1786	<.0001	AL*WB	-0.0047	0.01			
	Distal	0.71	1.777	<.0001	AL*D2P	0.0179	<.0001						
2 (index)	Proximal	0.67	1.607	0.003	HW	0.2326	<.001	D2P	-1.2867	<.01	AL*B2D	0.0113	0.03
	Middle	0.73	0.884	<.0001	HW*D2D	0.1045	<.0001						
	Distal	0.62	1.446	<.0001	AL*D2P	0.0138	<.0001						
3 (middle)	Proximal	0.62	-0.828	0.1553	HL	0.1817	<.0001						
	Middle	0.54	1.647	<.0001	AL*HW	0.0046	<.0001	HL*B2P	-0.0302	0.01			
	Distal	0.73	1.408	<.0001	AL*D2P	0.0171	<.0001	G	-0.1864	0.01			
4 (ring)	Proximal	0.55	1.406	<.0001	HL*HW	0.0086	0.0001	D2D*B2P	-0.2221	0.03			
	Middle	0.80	0.651	0.0034	AL*HW	0.0055	<.0001	HW*B2P	-0.0354	0.03			
	Distal	0.56	1.706	<.0001	AL*D2D	0.0138	<.0001						
5 (pinky)	Proximal	0.63	0.114	0.693	HW	0.2721	<.0001	HW*B2P	-0.0435	<.01			
	Middle	0.57	0.054	0.8724	D2D	1.6538	<.0001	AL*WB	-0.0027	0.01			
	Distal	0.55	0.571	0.0994	AL	0.0380	<.0001						

Table 2: Regression Coefficients, *p*-values, and R^2 Values for Phalange Lengths (cm). AL: arm length, HL: hand length, HW: hand width, WB: wrist breadth, D2P: depth at 2nd proximal IP joint, B2P: breadth at 2nd proximal IP joint, D2D: depth at 2nd distal IP joint, B2D: breadth at 2nd distal IP joint, and G: gender.

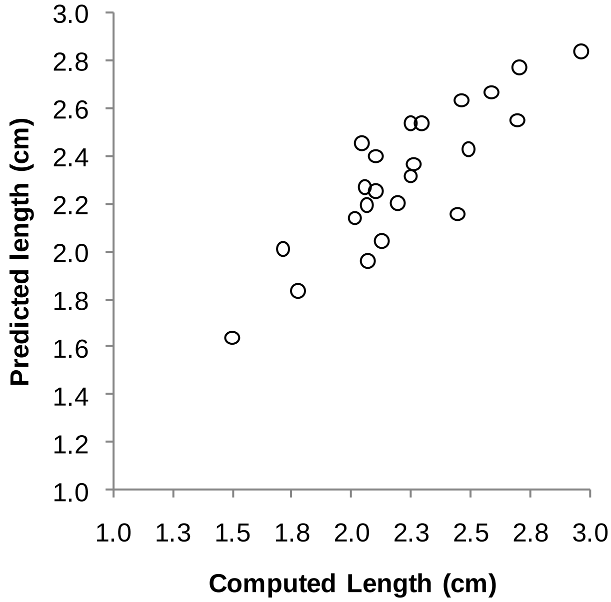

Figure 5: Computed versus Predicted Length of the 4th Middle Phalange.

Aim 3: *CAD model*

Progress toward achievement

The kinematic model developed in Aim 1 and the scaling library developed in Aim 2 has been integrated into the CAD model, allowing the hand to scale to population percentiles (Figure 6). Additionally, the model can be posed in a variety of configurations (Figure 7).

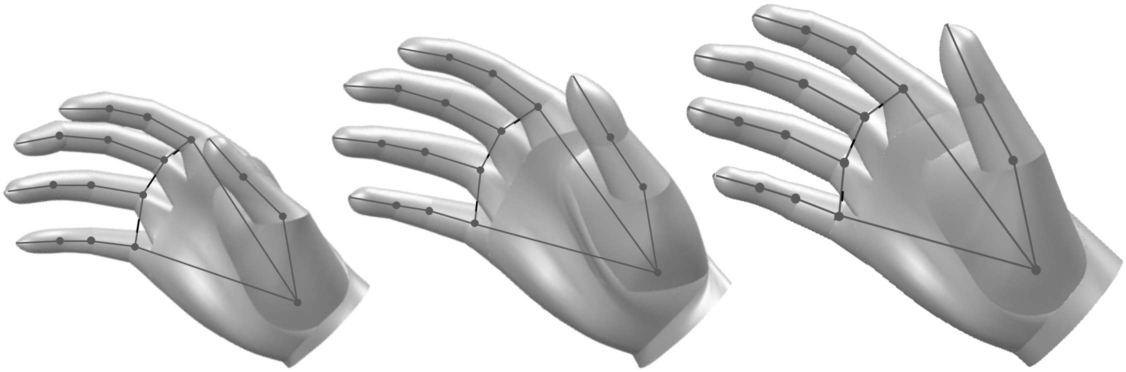

Figure 6: The CAD Model with the Joint Centers and Surface Topography Scaled to the 25^{th}, 50^{th}, and 75^{th} %tiles.

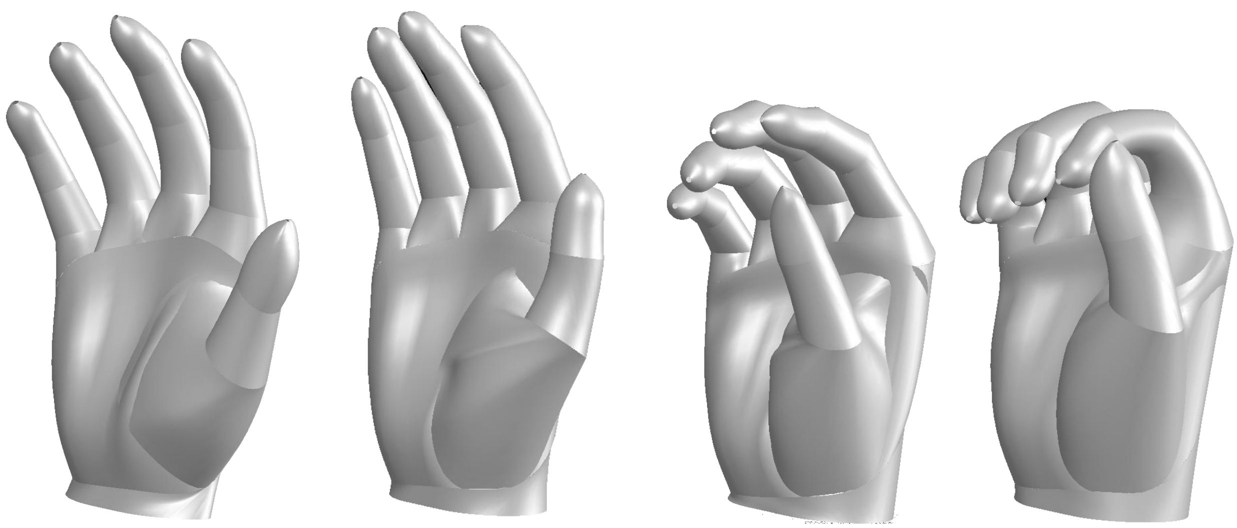

Figure 7: The CAD Model Posed in Example Configurations.

Importance of the findings

This existing CAD model, which integrates the kinematic and surface topography sub-models, provides the framework for integrating the two remaining models (kinetic and predictive). The fully integrated CAD model will allow for optimizing the design of tools and interfaces to reduce risk and increase access and functionality.

Publications from the Phase I of SBIR:

A manuscript, to be submitted to a peer reviewed journal such as *Ergonomics*, is currently being written.

Technology to be developed from this SBIR:

An integrated suite of software models will be developed to predict the interaction, and hence risk, access, and functionality, of a hand with a specific tool or interface. Consider an engineer/designer working with a piece of 3D geometry that represents a new hand held device. With the proposed integrated suite of models, that engineer/designer may call up different sized animated hands in the same CAD environment as the new device and accurately place the device within the hand based on hand contact points and visual requirements. The software program will allow the engineer/designer to visualize the feasible design space (e.g. the work volume of the thumb) related to trigger/switch positions and grasp contacts of the device. An iterative process, wholly with use of a computer, can thus be used to generate an optimized design that decreases risk from awkward postures and increases access and functionality through optimized geometry of the device. It is expected that such an iterative process prior to prototyping should generate prototype designs that are based heavily on empirical evidence (and perhaps less on intuition).

Current Status of the Product:

The product, which consists of a suite of integrated computer models to optimize manipulated devices, is under development. The kinematic (skeletal) model has been generated. The CAD model integrating the kinematic and the unloaded skin topography models has also been generated. Technical aspects of Phase II of the project will include the development of the remaining models, specifically the kinetic (skin-deformation) and predictive (actual grasp strategy) models, which will be integrated into the existing CAD model.

SBIR Grant benefits to Ozen Engineering:

This grant helped Ozen Engineering, Inc. establish relationships with UC Berkeley; enabling access and establishing bridge between academia and industrial application. If follow-up funding is approved, Ozen Engineering, Inc. will be able to develop an add-on to any commercial CAD package (like Autodesk Inventor) such that a hand solid model will be made available inside these CAD packages. This grant also helped Ozen Engineering, Inc. increasing technical expertise in linking research to an industrial solid modeling capability. Further funding will also enable a software license agreement between Ozen Engineering, Inc. and established CAD software companies like Autodesk, Inc.

Current number of employees:

Currently, Ozen Engineering, Inc. employs 4 full-time, 1 part-time, and 4 contract employees.

Reference:

Rogers MS, Barr AB, Kasemsontitum B, Rempel DM. A three-dimensional anthropometric solid model of the hand based on landmark measurements. Ergonomics 2008;51(4):511–526.