

Optimization-Based Grasp Posture Generation Method of Digital Hand for Virtual Ergonomics Assessment

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ABSTRACT

Automatically generating humanlike grasp postures of the digital hand is a key issue for the virtual ergonomic assessment of the industrial products. In this paper we propose a new optimization-based approach for generating the realistic grasp posture. As an objective function, we use the number of the contact points, the fit of the specific part of the hand surface for the feature edges of the product surface and the margin for the constraints on the joint angle limits of the figures. The experimental studies on the grasp posture generation for the digital camera indicate that more realistic grasp posture could be generated using the proposed optimization-based method than the one using our former method.

INTRODUCTION

Recently, the manufactures of handheld information appliances have had to refocus their attention on the ergonomic design in order to differentiate their products and to gain competitiveness in the market. The ergonomic design of information appliances can be separated into two main categories: physical and cognitive. The physical aspect of the ergonomic design of these appliances includes easiness of grasping the housing, relevance of arranging the positions of physical components (buttons, switches, dials, displays lumps etc.) on the user-interface, and the ease of their manipulations. The assessment of the physical aspect usually requires subjects to test the physical mockups of the appliance.

However, the cost of fabricating the physical mockups usually becomes expensive, and its fabrication takes a long time. The manufacturer would like to cut these

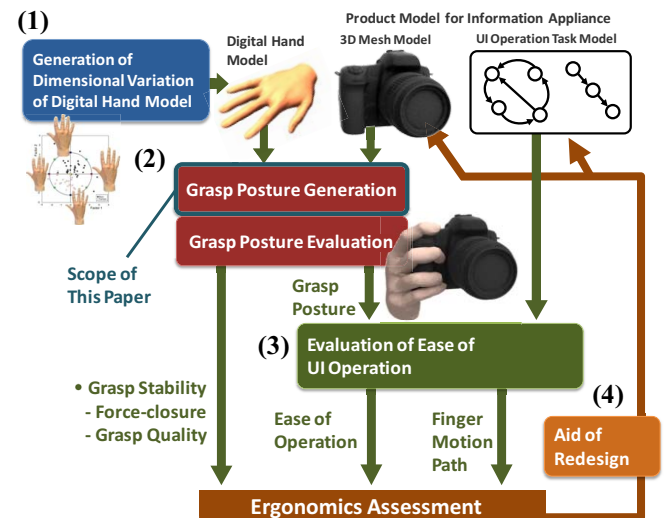


Figure 1. The overview of our proposed ergonomic assessment system

costs and decrease the development period while taking the ergonomic design of the product into consideration.

To cut these costs and to decrease the developmental period, many 3-D CAD systems have spread widely to the design process of these information appliances. And the 3-D digital mockup of the housing of the appliances can be easily obtained in the early design stage. So there is a strong possibility that we can execute the ergonomic assessments by integrating digital human models, especially including the digital hand models, with digital mockups of the appliances to decrease the extra time and cost of making physical mockups.

Some simulation software using digital human models has been commercialized [1] and is being used in the design of automobiles and airplanes. However, the digital hand models included in these commercialized software do not necessarily comply with the

desired accuracy and size variation of human hands when evaluating the relevance of grasping and operating the handheld appliances.

Therefore, the purpose of our research is to develop a virtual ergonomic assessment system for designing handheld information appliances by integrating the digital hand model with the 3-dimensional product model of the appliance.

As shown in Figure 1, in our system, we realize the following features and functions necessary for ergonomic assessment:

1. Generation of kinematically and geometrically accurate 3-dimensional digital hand models with rich dimensional variation: We apply a digital hand model called “Dhaiba-Hand” [4] to the ergonomic assessment in our system. The Dhaiba-Hand was developed by DHRC, AIST, JAPAN. The Dhaiba-Hand has a very precise hand link structure model which is derived from the kinematic analysis for the measured data obtained from motion capture and MRI[2,3]. 3-D digital hand models with dimensional variation can be generated by deforming a generic hand model which has been created by the factor analysis of dimensional measurements taken from 103 Japanese subjects’ hands [4].
2. Automatic generation and evaluation of the grasp posture: By only inputting a few user-interactions, our system automatically generates one of the possible grasp postures determined by the product shape and the digital hand geometry. It also quantitatively evaluates the indices of the grasp stability for the product geometry, which is calculated based on the force-closure and the grasp quality used in the grasp planning of robotics.
3. Automatic evaluation of ease of the finger motions in operating the user interface: The system automatically moves fingers of the digital hand by following an operation task model of the user-interface (e.g. which button has to be pushed). It also automatically evaluates ease of finger motions during operation of the user interface based on the flexion joint angles of fingers.
4. Aiding the designers to redesign the housing shapes and to change the placement of the physical components of user-interfaces (e.g. buttons, dials, displays) in the digital mockup: By the above two evaluation indices, the system conducts sensitivity analysis of these indices for some dimensional parameters of the housing. This analysis finds an optimal combination of some dimensional parameters of the housing shapes so as to maximize the evaluation indices for the grasp posture.

In this paper we mainly describe the above function 2, especially the function of generating the grasp posture.

RELATED WORKS

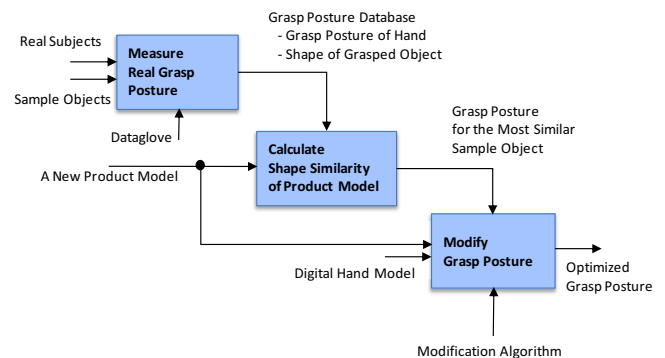
APPLICATION OF DIGITAL HAND IN ROBOTICS, VIRTUAL REALITY, AND COMPUTER GRAPHICS

Many researchers in robotics, virtual reality (VR), and computer graphics have proposed in applications for the digital hand model: a grasp planning system for robotic hand design [6,7], a VR environment for directly operating the virtual objects [9], a motion simulator for playing a music instrument [10], or a grasp posture generator for computer animation [11].

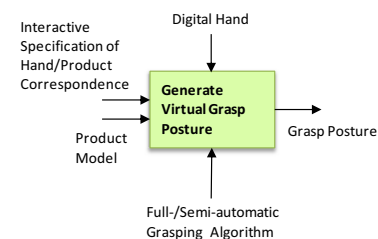
However, as described in our previous paper [18], these related works on the digital hand were not necessarily applicable to the ergonomic assessment of handheld information appliances because of the lack of accuracy of the model.

MEASUREMENT AND MODEL CONSTRUCTION OF A HUMAN HAND IN ANTHROPOMETRY

In anthropometry, Kouchi [4] developed a generation method of geometrically accurate digital hand models with rich dimensional size variation. These hand models can be generated by deforming a generic hand model which has been created by the factor analysis of dimensional measurements taken from 103 Japanese subjects’ hands. Miyata [8] developed a generation method for a precise hand link structure model which is derived from the kinematic analysis for the measured data obtained from motion capture and MRI. These methods are implemented as “Dhaiba-Hand” [4] which is



(a) A variant method



(b) A generative method

Figure 2. The comparison of the grasp posture generation methods of the related works.

a part of the full-body digital human modeling project “Dhaiba” [19].

GENERATION AND EVALUATION OF GRASP POSTURE

Some research [6,20,21,18,11,17] has proposed the generation and evaluation method of the grasp postures of the digital hand for the objects. As shown in Figure 2(a)(b), the representative approaches for generating the grasp posture are roughly classified into two types: a variant method [11,17] and a generative method [6,20,18].

In the variant method, the real grasp postures of many subjects for sample objects have been measured in advance using a dataglove to build a grasp posture database. Then, in the generations step, one grasp posture whose object shape is most similar to the given object model shape is chosen from the grasp posture database. The selected posture is modified to match the product model shape. If a very similar product shape can

be found in the database, a nearly appropriate grasp posture for the given product can be obtained after this modification process.

On the other hand, in the generative method, the grasp posture is generated by a full-/semi-automatic grasping algorithm. It does not need any database of real grasp postures. For any unknown shape, this method can generate a grasp posture that satisfies geometric conditions when the hand is contacting with the product surface.

However in related works using both methods, there have been some problems in regards to obtaining ideal grasping conditions in information appliances. For example, the variant method of Li [17] cannot generate the posture when their hand posture database does not include the shape of the product similar to a new one. On the other hand, our previous work [18] using the generative method sometimes fails to generate a desired grasp posture. The user needs to predict a few combinations of the user-input points which results in the successful grasp. However, it is difficult for the user to prospect the final grasp posture at input (see the section 3.4 for more detail). And, both of these researches did not discuss whether the obtained grasp postures were truly appropriate and possibly realistic one or not from the experiments.

OUR PREVIOUS WORK

DIGITAL HAND MODEL

To perform effective digital ergonomic assessment, it is insufficient to use only one digital hand model with a fixed dimension because the physical dimensions of the appliance users differ from person to person. Therefore, we needed to generate a digital hand model with possible anthropometric variation. In order to achieve this purpose, we used a digital hand model based on the Dhaiba-Hand [4]. The digital hand model used in our system consists of the following four parts and the relationship among these parts is shown in Figure 3(b):

1. **Link structure model:** A link structure model approximates the rotational motion of bones in the hand. The model was constructed from the measurement by MRI and the motion capture. The model has 17 links, and each link has two joints at both its ends. These joints can rotate with 1, 3 or 6 degrees of freedom, as shown in Figure 3(a).
2. **Surface skin model:** A surface skin model is a 3-dimensional polygonal mesh for the hand surface generated from CT images, as shown in Figure 3(a). The geometry of the skin model is defined at only one opened posture.
3. **Surface skin deformation algorithm:** This algorithm defines the deformed geometry of the surface skin