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A description of hand matrices to extract various characteristics of human hand in three-dimensional space

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ABSTRACT

This study focuses on a description of hand matrices to extract various characteristics of human hand in three-dimensional space. A mathematical expression for human hand has scarcely been proposed so far, and the practical, versatile description has been required to analyze a gesture behavior in detail. In this study, the bones and joints of human hand were explained supplementarily. After that, a CG model of human hand was created according to the anatomical structure. With reference to the model's structure, hand matrices were proposed to investigate poses, positions, and postural orientations of human hand in a uniform manner. The several examples were also discussed with appropriate illustrations. As a result, the characteristics of hand matrices were revealed in practically-possible cases; moreover, the mathematical treatments were theoretically versatile and simple to find a difference or common feature of hand motion in three-dimensional space.

1. Introduction

Human hand enables us to perform from daily-living activities to dexterous tasks. Although we usually use it without self-awareness, the bio-systems and functions have uninterruptedly attracted scientific interest from different perspectives. The interest has also induced a lot of studies regarding human hand in various fields such as biomechanics [1–3], biometrics [4–7], anatomy [8,9], computer graphics (CG) [10], robotics [11] and ergonomics [12]. Among the related fields, CG technologies have been widely used to model the behaviors of human hand as the visual imaging. Especially, three-dimensional (3D) hand modeling is well known as one of the remarkable technologies able to obtain the detailed understanding for human hand. Yasumuro et al. [13] reported a skeleton model based on the

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anatomical aspects of human hand. The model covered with polygon surface was applied to the hand animation which could display the natural posture and smooth movement. The anatomical aspects of human hand was also discussed by van Nierop et al. [14], and their study introduced a natural human hand model with a concept of natural joint axis. The model contributed to evaluating the biomechanical movement of human hand from taxonomical viewpoint. The visual evidences were also represented with the CG depictions.

On the other hand, mathematical description is indispensable to reveal the geometrical relationships in various behaviors of human hand. In practice, real-time 3D simulation and animation are depicted using calculation results with the description. Hence, various studies have been devoted to establish the mathematical description of human hand. Accordingly, the theoretical understanding has been enhanced in motion dynamics and analysis. Liu and Zhan [15] mathematically gave a description of hand postures, and the joint angles of each finger were evaluated using the measurement approach proposed in their study. They also discussed another mathematical approach considering the variation between different gestures. In their other work, they applied graph theory to human hand modeling and attempted to classify hand forms [16]. Cobo et al. [17] gave the detailed consideration for hand modeling. As a result, simplified hand descriptions were derived to analyze the position errors of manipulation tasks. Yang et al. [18] systematically classified the forms of human hand. The classification was based on set theory, and the verification was provided with some examples. It was also pointed out that existing methods for modeling hand kinematics were mostly based on cadaver measurements and optical surface tracking [19]. Then, a model of MRI-based skeletal hand movement was proposed with the biometrological consideration of several joint types.

Although the mathematical expression of human hand has gradually developed with various contributions, we are also unaware of a proper expression able to extract instantaneous poses, positions, and postural orientations in a uniform manner. The expression has been required to investigate human hand in further detail. In general, representing the motion of thumb finger is especially difficult due to its unique role. However, the most similar studies including the field of robotics give a single or double angle to a joint to express the motion. The expressions with a single or double angle at a joint are certainly possible to treat the simple motion, whereas it is impossible to specify the all motions with complexity. The same commonly holds for the other fingers. This fact is one of the motivations for this study. Hence, the purpose of this study is to provide a simple, universal description of human hand behaviors. With a consideration of skeletal hand model, matrix expressions will be introduced in this study; moreover, the characteristics will be explained with CG images.

The remainder of this paper is organized as follows: Section 2 describes a configuration of hand model with bones and joints; moreover, hand matrices are mathematically described in Section 3. Then, the several characteristics are reported in Section 4. Finally, Section 5 gives a conclusion with future work in this study.

2. Model configuration

This section describes a configuration of hand model with bones and joints. The bones and joints of human hand are supplementarily introduced according to the anatomical structure. Then, a CG model creation is explained with the setting of bones and joints.

2.1. *Skeletal structure of human hand*

Human hand mainly behaves as an eventual function integrating the motion of bones, muscles, tendons, and so on. Especially, the motion of bones and joints directly reflects the poses of human hand at any time. The positions and postural orientations are also important factors to characterize a gesture of human hand in 3D space. Before modeling human hand, this section supplementarily describes the skeletal structure with a hierarchical order. The skeletal structure is illustrated in Fig. 1. There are various bones and joints associated with five fingers and palm. The bones are composed of eight carpal bones, five metacarpal bones and fourteen phalanges which can be classified into proximal, middle, and distal phalanxes. As the joints, there exist carpometacarpal (CMC) joint, metacarpophalangeal (MCP) joint, proximal interphalangeal (PIP) joint, and distal interphalangeal (DIP) joint. Among several fingers, thumb only works with three bones which are two phalanxes and metacarpal. The carpus causes an intricate deformation since its eight elements articulate subtly with each other. The influence is actually small on the surface deformation [13], so that this study excludes it in the following sections.

2.2. *CG model and bone setting*

To extract characteristics of human hand, we create a CG model using 3ds Max released by Autodesk Inc. This software has useful environment for CG modeling, and the environment also

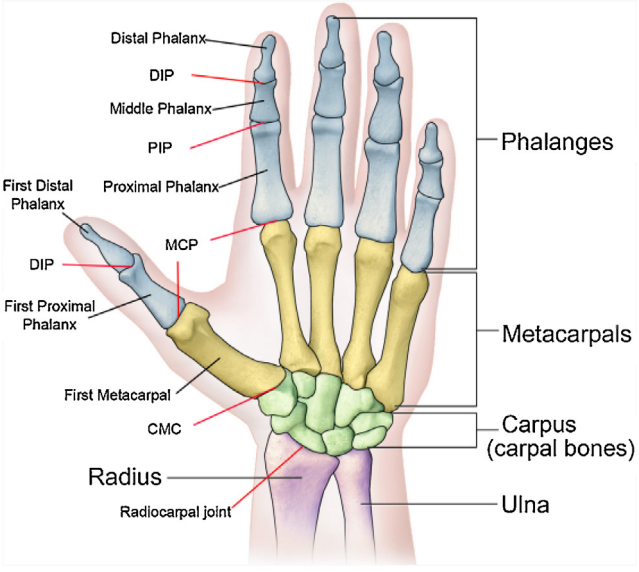

Fig. 1 – The bones and joints of human hand [10,20].

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