Reduced DoFs of Digital Hand Based on Anatomy for Real Time Operation

Hiroshi Hashimoto[1], Akinori Sasaki[2], Koji Makino[3] and Kaoru Mitsuhashi[4]
[1]*Advanced Institute of Industrial Technology, Shinagawa-ku, Tokyo, Japan*
[2]*Tokyo Metropolitan Industrial Technology Research Institute, Koto-ku, Tokyo, Japan*
[3]*University of Yamanashi, Kofu-shi, Yamanashi, Japan*
[4]*Tokyo University of Technology, Hachioji-shi, Tokyo, Japan*

Keywords: Digital Hand, Reduced DoFs, Hand Anatomy, Real Time Operation.

Abstract: This paper describes a model of using a digital hand, which mimics human hands, operates dynamically in real time operation. Focusing on real time operation, we consider a model structure of digital hand with reduced DoFs (degree of freedoms) as an approximated model, where the reduction is based on the anatomical and medical hand analysis. There some problems because of the approximated model. To overcome the problems, some techniques are implemented into the model. We examine how the model is able to mimic the movement of human hands.

1 INTRODUCTION

This paper describes a model of using a digital hand, which mimics human hands, operates dynamically in real time operation. Focusing on real time operation, we consider a model structure of digital hand with reduced DoFs (degree of freedoms) as an approximated model, where the reduction is based on the anatomical and medical hand analysis. We examine how the model is able to mimic the movement of human hands.

Many significant works on digital hand have been studied very well in the fields of robot hands, ergonomics on grasping objects, animation and so on(H.Kawasaki and K.Uchiyama, 2002),(Tetsuyou Watanabe and Jiang, 2006). The objective of the robot hand study has different view point from the structure of a human hand, because it it to grasp an object in stable situation (Nguyen, 1986), (T.Yoshikawa, 1996). In the animation, considering muscular, freedom of joints or tendons, a precise digital hand to mimic human hand is tried to be made(J.Lee and T.Kunii, 1995),(Shinjiro Sueda and Pai, 2003),(S.Mulatto and D.Prattichizzo, 2013), (Yui Endo and Shimokawa, 2002). Its objective is to evaluate product designs when it grasp an object. To do this, the discussions are made about parameter identifications of the digital hand, and grasping situation on contact points between the digital hand and object. These considerations focus on the static states while grasping statically, not dynamical states such as pen spinning.

On the other hand, the human hand is able to manipulate objects dexterously. For example, the human hand can pass an instrument from appropriate fingers to the other with only finger. Further, pen spinning operations give a much value as theater. These operations lead to a rapid use of the instrument or create much valuable things. The dynamical operation of the digital hand has been slightly considered in (H.Hashimoto and C.Ishii, 2013), (H.Hashimoto and Y.Ohyama, 2014), not seen in the other study. In the previous research, the body of the digital hand was made from rigid body.

Human hand is covered by soft skin, whichi is deformable while operating an object. Therefore, contact region touched with the object is area not point for rigid skin, so the dynamic relationship on the contact region also becomes complex. This means the real time operation of the digital hand requires numerous computational load.

Because the way of moving of is very enormous to operate a thing dynamically, it will program it every judging from the existing state of things to make the manual based on the program and is very troublesome. Manipulating the digital hand dynamically, it is too numerous paterns that its posture shows to real-

Hashimoto H., Sasaki A., Makino K. and Mitsuhashi K..
Reduced DoFs of Digital Hand Based on Anatomy for Real Time Operation.
DOI: 10.5220/0005099807640768
In *Proceedings of the 11th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2014), pages 764-768
ISBN: 978-989-758-039-0

ize it for various operation cases.

To overcome the problems such as the computational load with soft skin and real time operation for various operation cases, first, we propose a digital hand structure with reduced DoFs of joints based on anatomy. Second, the operation system with hand-posture sensor (LeapMotion, 2014) and virtual physical space which is realized with Bullet Physics (BulletPhysics, 2014). To confirm the effectiveness of the digita hand system, some operations are examined.

2 HUMAN HAND KINEMATICS MODELING

Based on anatomical and medical hand analysis of previous studies and research, the hand skeleton model has 23 internal DoFs (Figure 1) (Kapandj, 2008),(Zatsiorsky, 1998).

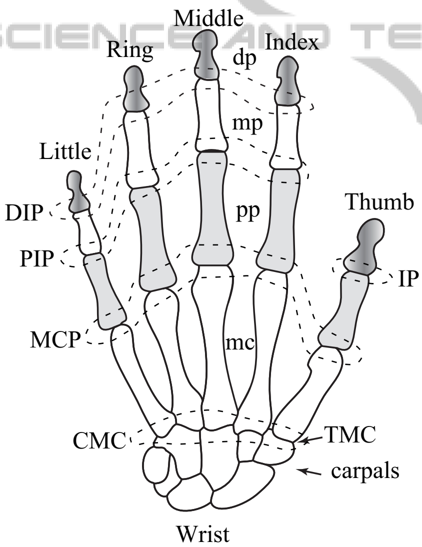

Figure 1: Hnad skelton structure.

Next, let us consider to reduce the DoFs to reach real-time operation with our system. Here, the dexterous pose and motion of hand should be kept in good condition such as the arches(N.Kamakura and Y.Miura, 1980),(S.J.Edwards, 2002). So, the DoFs of thumb needs to consider very carefully. The range of deviation of MCP joint of the thumb is so small for abduction/adduction that it can be usually neglected, and its DoFs can be approximated as one.

Not to force the action of bending the fingers, but to act for flexion/extension, there is an angular constraint condition between the angle of DIP and of PIP for each finger such as (E.Y.Chao and R.L.Linscheid, 1989), (Y.Wu and T.S.Huang, 2005).

$$\text{angle}\,(\text{DIP}) = \alpha\ \text{angle}\,(\text{PIP}) \tag{1}$$

where angle (joint) means the angle of joint and

$$\alpha \simeq \frac{2}{3} \tag{2}$$

From the fact, the angles of DIP and PIP are linearly independent, so one DoF for each finger can be reduced. Figure 2 shows the structures of the skeleton model under the consideration described above. As shown in Figure 2, the DoFs of four fingers is nnn each, the DoFs of thumb is mmm, and the total DoFs is llll, which attain to reduce iiiii from the original DoFs.

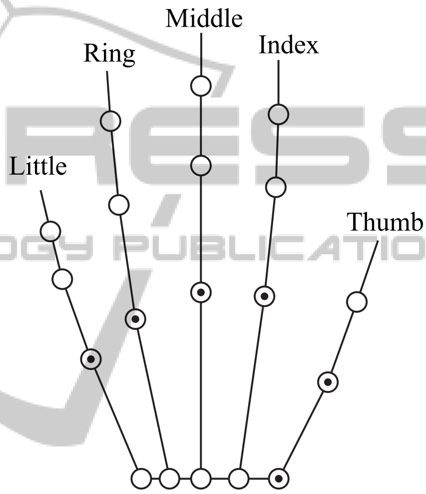

Figure 2: Structure model of joints and bones.

The model in Figure 1 is based on the anatomy. The DoFs will become more reduced to be suitable the input device described later.

3 STRUCTURE OF DIGITAL HAND

Human hands consist of rigid bone and soft skin which forms deformable surface when hand grasping objects. The rigid bone support to pick at a small object and the soft skin is to prevent to drop an object with friction on the contact area between deformable skin and the object. Therefore, a complex operation of human hand is realized. First, the design of the soft skin is described, then the its connection with rigid bone is shown.

3.1 Design of Soft Skin

In making the digital hand by using Bullet Physics as a physics engine, it is difficult to join soft skins to rigid bones. This is because the schemes of those collision detections are different.

From this, we think about only skin of the size that only comes in contact with the object. And the connection between the soft skin and the rigid bone uses an anchor combination of Bullet Physics, not direct combination. For this reason, the skin is designed to be able to installed onto the tip of the finger and the middle of each bone. The shape of the skin of fingertip is made by Blender (Blender, 2014) shown in Figure 3.

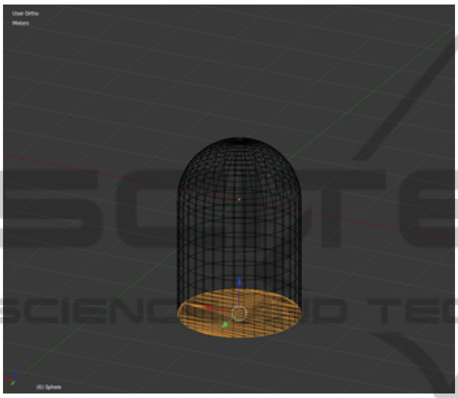

Figure 3: Making of Soft Skin in Blender window.

The number of mesh that make up part of the hemisphere finger tip and the finger pulp is too large, the calculation time required for collision detection is enormous, and it can not achieve real-time operation. Based on the trade-off of computational load and feasibility of the dexterous hand operation, the selection of the number is determined by trial and error.

Next, the figure of the soft skin is introduced into soft body of Bullet Physics, and some parameters (Table 1) of soft body should be defined to set up it.

However, the effective way to identify them have not shown yet, so we investigated that human hand played the bar spinning as a manipulation with the high-speed camera (1000 fps) as shown in Fig. 4. Investigating the deformable skin from it, the parameters are adjusted to show the same deformable soft skin.

Figure 4: Scene of bar spinning.

Table 1: Parameters of soft body in Bullet Physics.

kDP	Damping coefficient; damps forces acting on soft body nodes to reduce their oscillation over time. Imagine a mass hanging on a spring. Range [0,1]
kDG and kLF	Drag and Lift coefficient; relating to aerodynamics (see wikipedia pages for ”drag coefficient” and ”lift (force)”). Range [0,+∞]
kDF	Dynamic friction coefficient; just friction of nodes against surfaces, as with rigid bodies. Range [0,1]
kMT	Pose matching coefficient; be used with setPose(bool, bool). Range [0,1]
kCHR, kKHR and kSHR	Rigid, kinectic and Soft contacts hardness; controling how strict any overlap between the soft body and other types is treated. Range[0,1]

3.2 Combination of Skin and Bone

The bong is made from a cylinder rigid body and uses a motor as rotating joints, The DoFs is in accordance with the joint of the hand described the previous section. When the skin is connected with the bone, the gap of the joint is sufficient distance movable range of each joint to be achieved.

Figure 5 shows one finger conducted by the design described above.

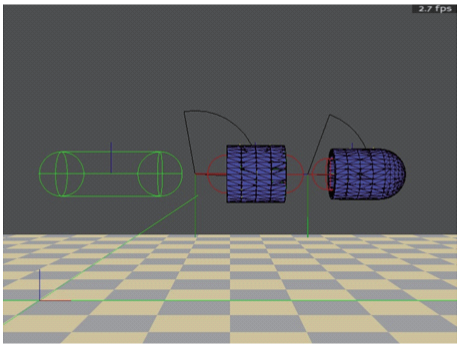

Figure 5: Digital finger with soft skin and rigid bone.

In Figure 5, the rigid bone and the soft skin are connected with anchors. Each anchor has a motor to rotate the joint, and it is controllable to appropriate reference angle or velocity.

Figure 6 shows the extending this configuration to the five fingers.

For through hand operation in real time, and is focused on seeing the mechanical interaction of the

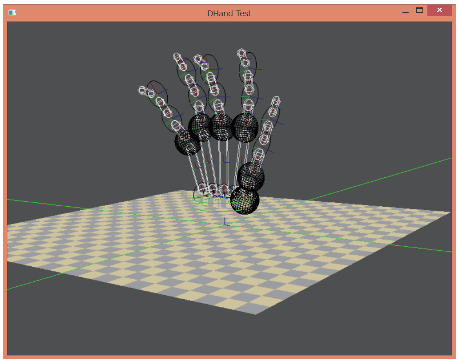

Figure 6: Digital hand.

hand and the object, this paper will not be rendered.

Because we focus on operating the digital hand in real time and investigating the dynamical interaction with the object, the rendering of CG is not introduced.

3.3 Virtual Physical Space

Our digital hand is able to grasp and manipulte objects in the Virtual Physical Space. In the development with Bullet Physics, the space would be not well defined yet. So, we define it such that the Virtual Physical Space is the three-dimensional extent shown in the computer simulation, in which an approximate simulation of certain physical systems, such as rigid body dynamics (including collision detection), soft body dynamics is provided by a proper physics engine.

The digital hand and appropriate objects are set in the Virtual Physical Space, then gravity, collision detection and rotation calculations for them are calculated. So, in the space the digital hand is able to grasp or manipulate the object.

4 REAL TIME OPERATION SYSTEM

4.1 Hand Posture Sensing

In this study, the Leap Motion Controller (LMC) is introduced as a hand posture sensing device (LeapMotion, 2014), (LeapMotionSDK, 2014).

The LMC is able to detect some informations of finger such that the position of finger tips and the direction vector of fingers, but not the joint angles of the finger. As informations of the palm, the LMC is able to detect the normal vector to the palm. If the hand is flat, the vector will point downward. When the hand becomes grasping posture, then the shape of parm is assumed to be arch and the virtual sphere is placed as if the hand were holding a ball by posturing the arch. Then, the center position of the sphere is detected.

From the hand informations described above, the posture of hand is able to estimated what are open, holding and arch (LeapMotionSDK, 2014). In those posture, we use the approximated posture whose joints are linearly dependent such as

$$\mathrm{angle}(\mathrm{MCP}) = \beta\ \ \mathrm{angle}(\mathrm{DIP}) \qquad (3)$$

and

$$\mathrm{angle}(\mathrm{CMC}) = \gamma\ \ \mathrm{direction}(\mathrm{DIP}) \qquad (4)$$

for holding. Where direction(finger) means the absolute of the direction vector of the finger, β and γ are defined from the examination of hand operating.

4.2 Implementation

A demonstrative application was developed to evaluate the digital hand in operation by the postures. The goal is to set up the digital hand in real time operation. The software application is executable on the CPU(Core i7-4900MQ, 2.8GHz) and the GPU(Nvidia Quadro K4100M, 1152 Cuda processors). In our goal, the roles of CPU and GPU are assigned separately as following

- Finger Callback : CPU
- Graphics Thread : GPU
- Physics Simulation : GPU

These processing assigned to CPU and GPU is enable to use PyCUDA(PyCUDA, 2014), the assigned has been developing in the present circumstances.

4.3 Experiment

The operator is operate the digital hand in real time,using the Leap Motion as the input device of the human hand posture as shown in Figure 7 According

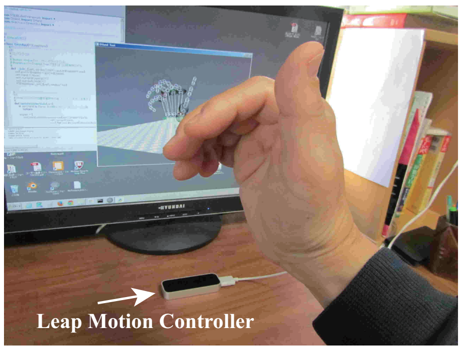

Figure 7: Digital hand system with input device Leap Motion.

to the movement of human figures and palm of the hand, the digital hand change its posture to mimic the hand in real time. And when the digital hand grasp an object in the virtual physic space, the collision detection between the digital hand and the object is transmitted to the physics engine, and the digital hand can grasp it according to the varying hand posture in real time.

5 CONCLUSIOIN

This paper proposed a novel design procedure of the digital hand, which is in reduced DoFs, the design of soft skin, rigid body and those connection approach, and real time operation system.

The reduced DoFs of the digital hand is proposed by considering anatomy, which is to be operated in real time. The total number of reduced DoFs is 16, which is less than six degrees of actual DoFs.

The design of soft skin and rigid body is regular way in CG creation, but the connection approach is devised because the collision detection of each body shows different phases. This approach relates on the shape of the soft skin.

The real time operation is considered about the digital hand with reduced DoFs and the usage of the LMC. To use the cheaper devices will expand our system to ordinary users. So, we have been developing the real time operation system, and the applicable demostration to show the real time operation will be shown.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Gran Numbers 25280125, 25560009 and in part supported by JST RISTEX Service Science, Solutions and Foundation Integrated Research Program.

REFERENCES

Blender (2014). http://www.blender.org/.

BulletPhysics (2014). http://bulletphysics.org/.

E.Y.Chao, K.N.An, W. and R.L.Linscheid (1989). *Biomechanics Of The Hand*. World Scientific Publishing.

H.Hashimoto, A.Sasaki, S.-K. and Y.Ohyama (2014). A structure and soft finger model of digital hand for real-time dexterous manipulation. In *Proc. of IASTED International Conference on Modelling, Identification and Control*, pages 265–270.

H.Hashimoto, A.Sasaki, S.-Y. and C.Ishii (2013). Bar spinning as dexterous manipulation of digital hand based on human hand. In *The 23rd IASTED International Conference on Modelling and Simulation*, pages 413–418.

H.Kawasaki, T. and K.Uchiyama (2002). Dexterous anthropomorphic robot hand with distributed tactile sensor: Gifu hand ii. In *IEEE/ASME Trans. on Mechatronics*, volume 7, pages 296–303.

J.Lee and T.Kunii (1995). Model-based analysis of hand posture. In *IEEE Computer Graphics and Applications*, volume 15, pages 77–86.

Kapandj, A. I. (2008). *The Physiology of the Joints Vol.1-3*. Churchill Livingstone.

LeapMotion (2014). https://www.leapmotion.com/.

LeapMotionSDK (2014). https://developer.leapmotion.com/.

Nguyen, V. (1986). Constructing stable force-closure grasps. In *Proc. of ACM Fall Joint Computer Conf.*, pages 129–137.

N.Kamakura, M.Matsuo, H.-F. and Y.Miura (1980). Patterns of static prehension in normal hands. In *The American Journal of Occupation Therapy*, volume 34, pages 437–445.

PyCUDA (2014). http://mathema.tician.de/software/pycuda/.

Shinjiro Sueda, A. K. and Pai, D. K. (2003). Musculotendon simulation for hand animation. In *ACM Transactions on Graphics, SIGGRAPH 2008*, volume 27.

S.J.Edwards, D.J.Buckland, J.-P. (2002). *Developmental and Functional Hand Grasps*. Slack Inc.

S.Mulatto, A.Formaglio, M. and D.Prattichizzo (2013). Using postural synergies to animate a low-dimensional hand avatar in haptic simulation. In *IEEE Transactions on Haptics*, volume 6, pages 106–116.

Tetsuyou Watanabe, Kensuke Harada, T. Y. and Jiang, Z. (2006). Towards whole arm manipulation by contact state transition. In *Proc. of the IEEE Inter. Conf. on Intelligent Robots and Systems*, pages 5682–5687.

T.Yoshikawa (1996). Passive and active closures by constraining mechanisms. In *Proc. of IEEE International Conference on Robotics and Automation*, volume 2, pages 1477–1484.

Yui Endo, Satoshi Kanai, N. M. M. K. M. M. J. K. M. O. and Shimokawa, M. (2002). Optimization-based grasp posture generation method of digital hand for virtual ergonomic assessment. In *SAE international journal of passenger cars-electronic and electrical systems*, volume 1, page 1.

Y.Wu, J. and T.S.Huang (2005). Analyzing and capturing articulated hand motion in image sequences. In *IEEE Trans. on Pattern Analysis and Machine Intelligence*, volume 27, pages 1910–1922.

Zatsiorsky, V. M. (1998). *Kinematics of Human Motion*. HUMAN KINETICS.