A Digital Hand to Mimic Human Hand in Real Time Operation
Making of Digital Finger with Partial Soft Skin and Rigid Bone

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Abstract: This paper presents a digital hand which is a type of model to mimic human hand operation in real time operation. Human hand performs various difficult tasks in daily life and shows dexterous operation to use tools or equipment, because it has numerous degree of freedom (DoFs) of finger joints and soft skin. To realize the mimic of human hand operation in real time operation to overcome the problems such as high DoFs, soft skin. We have developed the digital hand whose input to control hand posture is obtained from a hand posture sensor and soft skin is designed as mesh structure. Here, the way to define parameters of mesh structure is discussed. We demonstrate the simulation of the digital hand model and examine how the model is able to mimic the motion of human hand.

1 INTRODUCTION

This paper presents a digital hand with soft skin which is a type of model to mimic human hands in real time operation.

Human hand performs various difficult tasks in daily life and shows dexterous operation to use tools or equipment, because it has numerous degree of freedom (DoFs) of finger joints more than 22 DoFs (Chao et al.,1989), (Kapandj, 2005). There are many types of grasp such as power grasps, precision grasps and miscellaneous grasps, and each types is also divided into many various hand postures (Edwards and Buckland,2002). These hand postures can be made by the hand's DoFs, basically the posture of holding and arch ensure the various hand posture. However, a study on dynamical operation of hand using objects has not been made in the field of anatomy, but only on grasping which shows static situation to fixe objects.

On the other hand, the previous studies on digital hand for robotics or CG (computer graphics) have been developed very well. In the early period of robot hand researches, its objective is to realize stable grasping objects based on the theoretical aspects (Nguyen,1986), (Yoshikawa,1996). Hence, these consideration merely focused on the stable grasping geometrically, not consideration of the human like grasping/operations. Up to date, dexterous grasping of robot hands have been developed (Mouri et al., 2005), (Ishihara et al., 2006), (Inoue and Hirai, 2009), it remains difficult to realize dexterous manipulations as seen in actual human hand operations.

In researches of CG, considering muscular, freedom of joints and tendons, a precise digital hand to mimic human hand has been tried to be made (Lee and Kunii, 1995), (Sueda et al., 2008), (Endo et al., 2008), (Mulatto et al., 2013). Its objective is to evaluate product designs when it grasp an object. So, the discussions were 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 on dynamical states such as pen spinning.

Here, the human hand is able to manipulate objects dexterously described below. For example, the human hand can pass a tool from appropriate fingers to the other with only finger, this can be seen such that a skilled engineer operates a driver with one hand or a surgeon shows the neat exactness of the surgeon's knife. These operations lead to a rapid use of the instrument or create much valuable things.

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The dynamical operation of the digital hand has been slightly considered in (Hashimoto et al., 2013), (Hashimoto et al., 2014), not seen in the other studies. In the researches, the body of the digital hand was made from rigid body. Human hand is covered by soft skin, which 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 to operate a thing dynamically is very enormous, the programming to simulate all patterns of hand postures is very troublesome.

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 based on anatomy, here, the reduced DoFs of joints is introduced to decrease the computational load. Second, the operation system with hand-posture sensor LeapMotion (LeapMotion, 2015) and virtual physical space which is realized with Bullet Physics (BulletPhysics, 2015). To confirm the effectiveness of the digita hand system, some operations are examined.

2 SKELETON MODEL BASED ON ANATOMY

The hand skeleton model is shown in Figure 1 based on anatomical and medical hand investigation (Kapandj, 2008).

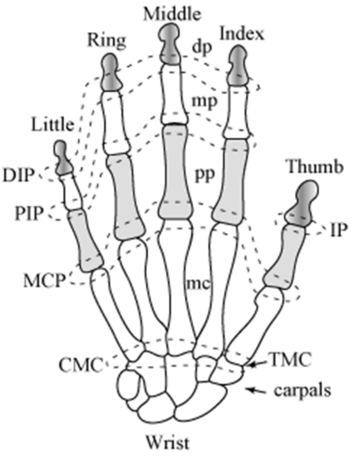


Figure 1: Hand skeleton structure.

In Figure 1, abbreviated label for joints have following meanings (arranged in order from proximal to distal extremity). CMC stands for the carpometacarpal joint, MCP for the metacarpophlangeal joint, PIP for the proximal interphalangeal joint, and DIP for the distal interphalangeal joint. Other joint labels of thumb are: TMC for the trapeziometacarpal joint, MCP for the metacarpophlangeal joint, and IP for the interphalangeal joint.

Degrees of freedom of each joint is approximately equivalent to those of the actual human hand, except the TMC joints because of complexity of joint structure of the actual human thumb.

The skeleton has five fingers, i.e., the thumb, index finger, middle finger, ring finger, and little finger. The base of these fingers in the hand structure is the carpus underneath the metacarpal bones, which lies between the palm and wrist. The carpus consists of 8 bones in the actual human hand but is approximated as two bones in the model: one corresponding to trapezium at bottom of thumb, and the other corresponding to other carpal bones except trapezium bone (assembly of other carpal bones, namely scaphoid, lunate, capitate, triquetrum, pisiform, trapezoid, and hamate bones).

Although metacarpal bones are all in the palm in an actual hand, they are all separated to allow motion relative to each other, and connected to a corresponding phalangeal bone of each finger.

Each finger (not including the thumb) is composed of three bone links, called phalangeal bones. Each neighbouring pair of bone links are connected with a joint, i.e. a constraint that restricts relative translational motion of bone links in dynamics simulation. The DIP, PIP and IP has one DoF, the MCP has two DoFs, the CMC has two DoFs and the TMC has three DoFs. So, the total DoFs of human hand is 30.

Here, the dexterous pose and motion of hand should be kept in good condition such as the arches (Kamakura et al., 1980), (Edwards and Buckland, 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 refs. (Chao et al., 1989); (Ying et al., 2005).

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

where the function angle(joint) means the angle of joint and

$$\alpha \simeq \frac{2}{3} \qquad (2)$$

Thus, the DoFs of DIP is able to be eliminated.

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, and the total DoFs is reduced to 16 from the original DoFs. In this figure, the dependent joints means that DIP is dependent joint to PIP as shown Equations (1) and (2), so the DoFs of DIP is able to be eliminated.

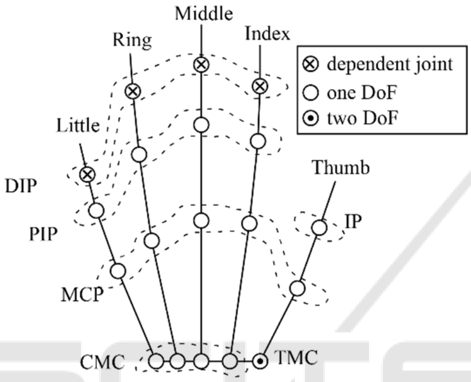


Figure 2: Structure model of joints and bones.

The reduced DoFs will be used in stable control of the digital hand 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 its connection with rigid bone is shown.

3.1 Design of Soft Skin

It is difficult to join soft skins to rigid bones in making the digital hand by using Bullet Physics which is one of physics engines. This is the reason why each schemes of collision detections is different.

Now, we think about only skin of the size that only comes in contact with the object, the connection between the soft skin and the rigid bone uses an anchor combination provided of Bullet Physics, not direct combination. From this, the skin is designed to be able to be 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, 2015) shown in Figure 3.

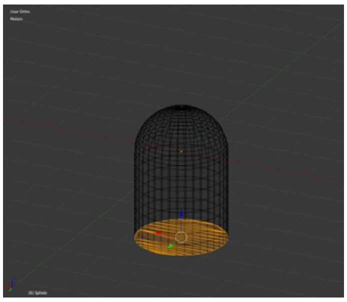


Figure 3: Making of soft skin of fingertip in Blender window.

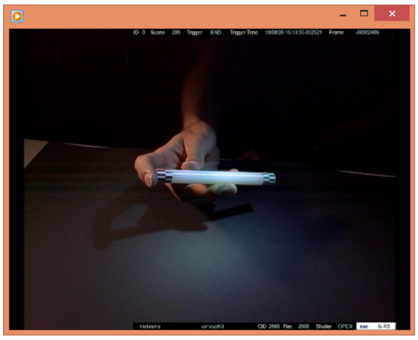
The number of mesh that makes up part of the fingertip and the finger pulp hemisphere will become too large, then the calculation time required for collision detection will be enormous, thus it is difficult to achieve real time operation. Based on the trade-off of computational load and feasibility of 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.

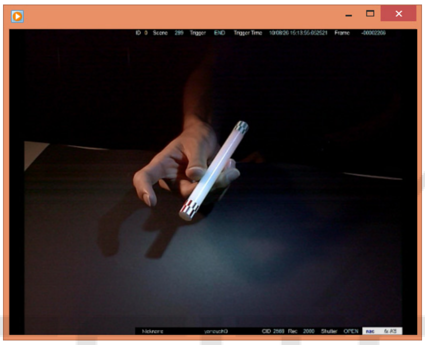
Table 1: Parameters of soft skin in Bullet Physics.

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 (Wikipedia_Lift,2015, NASA,2015), Range $[0, +\infty]$
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]

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 Figure 4. Observing the situation of the deformable skin by investigating the figure, the parameters are adjusted to show the similar situation of the deformable soft skin.



(a) t = 0.0 sec



(b) t = 0.1 sec

Figure 4: Scene of bar spinning (1000 fps).

3.2 Connection between Soft Skin and Rigid Bone

The bone is made from a cylinder rigid body and 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.

We use Panda3D (Panda3D, 2015) to develop the digital hand, which is a development platform with Bullet Physics, described in Python language. Figure5 shows one finger conducted by the design described above by using Panda3D. In Figure 5, the rigid bone and the partial soft skin are connected with anchors. The reason why the partial soft skin is adopted is to reduce the computational effort.

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

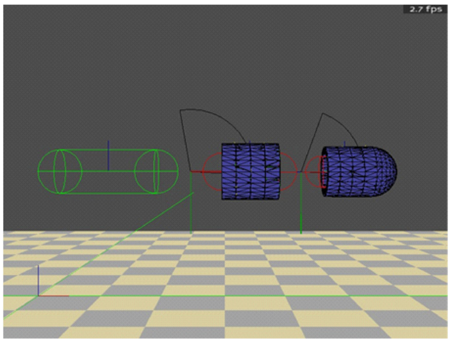


Figure 5: Digital finger with partial soft skin and rigid bone.

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

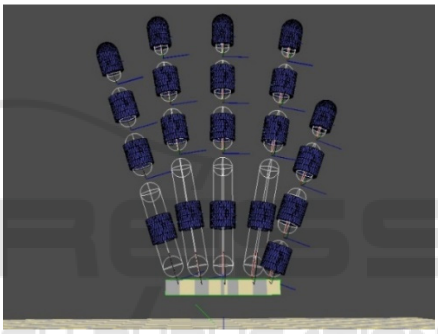


Figure 6: Digital hand with partial soft skin and rigid bone.

3.3 Virtual Physical Space

Our digital hand is able to grasp and manipulate 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

To realize the digital hand to mimic human hand operation in real time, a sensor which is able to sense the hand posture and also the position of hand is required, then the Leap Motion Controller (LMC) is suitable for the requirement. The LMC observes a roughly hemispherical area, to a distance of about 1 meter, and can get 3D position data of all joints of fingers and palm within sampling rate 150-295 fps (USB 3.0 connection), this is made possible by the skeleton model of hand of the LMC (LeapMotionSDK, 2015). Then, the position data is sent through a USB cable to the host computer.

The position data sometime is disturbed caused by light illumination or characteristics of human hand such as skin color and condition. To get stable data, the constraint condition shown in chapter 2 is imposed upon the data.

4.2 Implementation

A demonstrative application has been 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, 2015), because Panda3D is built in Python and the assigned has been developing in the present circumstances.

4.3 Experiment

The subject operates the digital hand to mimic the human hand in real time processing, using the Leap Motion as the input device of the human hand posture is shown in Figure 7.

We have succeeded in the real time operation for a Digital hand only with rigid bones, not soft skin as shown in Figure 8. The digital hand grasps and operates the bar dextrously. A scene of real time operation of the digital hand with rigid bones and soft skin is shown in Figure 9. According to the movement of human figures and palm of the hand, the digital hand change its posture to mimic the hand. 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. However, those computational load becomes tremendous, so the real time operation be fit to use is not sufficient.

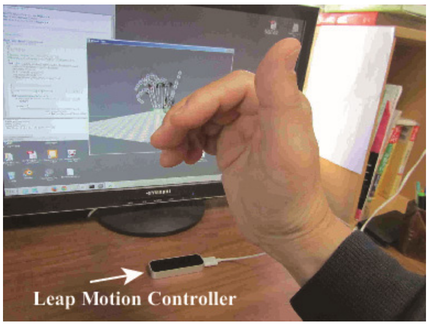


Figure 7: Digital hand system with LMC to get hand posture in real time.

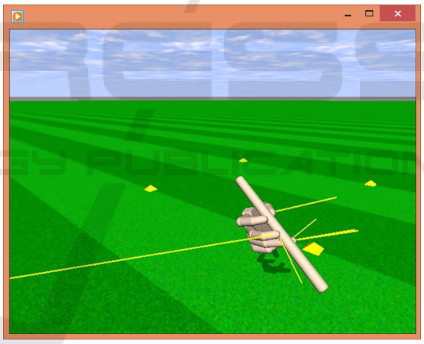


Figure 8: Digital hand with no soft skin operating the bar.

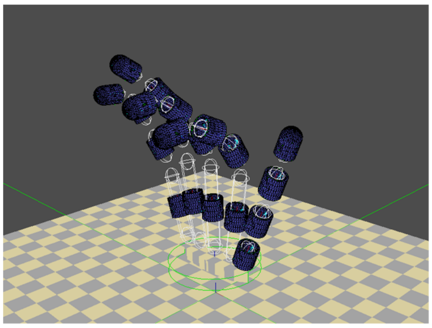


Figure 9: Digital hand with partial soft skin and rigid bone.

5 CONCLUSIONS

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 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. The applicable demonstration in real time operation is able to be realized by tuning PyCUDA, and it will be shown in the conference stage.

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