Consistent Grasping Interactions with Virtual Actors Based on the Multi-sensor Hand Model

Serge Rezzonico[1], Ronan Boulic[1], Zhiyong Huang[1]
Nadia Magnenat Thalmann[2], Daniel Thalmann[1]

1) LIG - Computer Graphics Lab, Swiss Federal Institute of Technologies
Lausanne, CH-1015 Switzerland
fax: +41-21-693-5328
email: {rezzoni; boulic; huang; thalmann}@lig.di.epfl.ch

2) MIRALab-CUI, University of Geneva, 24 rue du Général Dufour
Geneva, CH -1211 Switzerland
fax: +41-22-320-2927
email: thalmann@cui.unige.ch

Abstract

This paper proposes a general framework to enhance grasping interactions of an operator wearing a digital glove. We focus on a consistent interpretation of the posture information acquired with the glove in order to reflect the grasp of virtual artifacts. This allows manipulations requiring a higher skill in virtual environment and also improve interactions with virtual human models. A handshake case-study highlights the application range of this methodology.

key words : grasping, virtual human, digital glove

1 Introduction

With the advents of synthetic actors in computer animation, study of human grasping has become a key issue in this field. The common used method is a knowledge based approach for grasp selection and motion planning [RG91]. It can be completed with a proximity sensor model [EB85] or a sensor-actuator model [vdPF93] for the precise position control of the fingers around the object [MT94]. This method results in an automatic grasping procedure. Moreover, due to the 3D interactive tools widely available today, we decided to study interactive grasping of virtual objects while wearing a digital glove device. Such an approach is also interesting for Virtual Reality where more elaborated hand interaction is now possible with recent generation of digital glove. way In this context, we map the real posture of the digital glove on a sensor-based virtual hand in order to ensure a consistent collision-free grasping of virtual objects and to provide a consistent visual feedback. In a second stage, this process can drive the grasp behavior of a virtual human model with a classical inverse kinematic control applied to the arm, or a larger fraction of the body [PB90]. More elaborated control approaches of the arm have been proposed but this is beyond the scope of this paper (see [L93], [HBMTT95]). Both automatic and interactive grasping are integrated within the TRACK system [HBMTT95] hence allowing such grasping interaction as a handshake of an operator with a virtual human model.

We first recall the principle of the multiple virtual sensor grasping prior to develop the consistent virtual grasp with the digital glove. The framework of interactively driving the grasp behavior of a virtual human model is then outlined and a case study is presented. A discussion summarizes the performances, the interest and the limitations of the current state of the system. A short section presents the implementation details prior to the general conclusion.

2 Automatic Grasping with Multiple Virtual Sensors

This section briefly recalls the interest of automatic grasping based on virtual sensors (without digital glove). Our approach is adapted from the use of proximity sensors in Robotics [EB85] and the sensor-actuator networks [vdPF93]. More precisely, we use multiple spherical sensors for the evaluation of both touch and distance characteristics as proposed in [MT94]. They were found very efficient for synthetic actor grasping problem. Basically, a set of sensors is attached to the articulated figure. Each sphere sensor is fitted to its associated joint shape, with different radii. The touch property of any sensor is activated whenever colliding with other sensors or objects (except the hand components). This is especially easy to compute with spherical sensors (Figure 1).

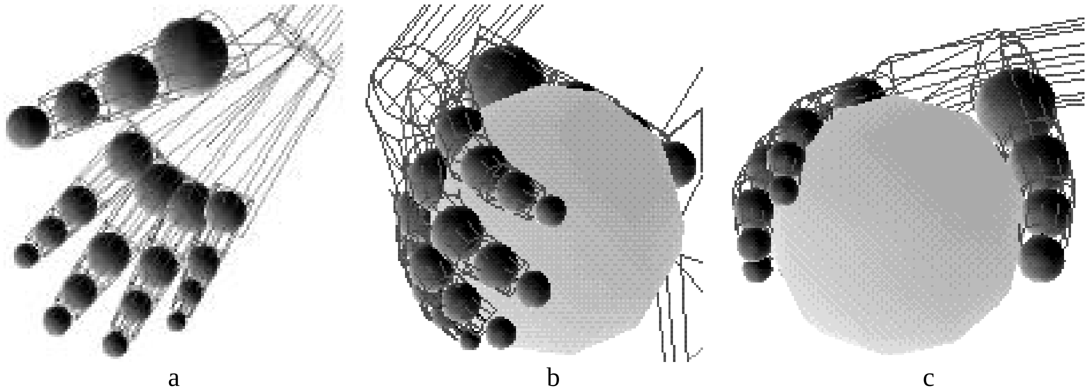

Figure 1. The virtual hand with sphere sensors (a); while grasping a sphere (b, c)

The sensor configuration is important in our method because, when the touch property of a sensor is activated in a finger, only the proximal joints are locked while distal joints can still move. In such a way, all the fingers are finally wrapped around the object, as shown in Figure 1b,c. When grasping a free form surface object, the sphere sensors are detecting collision with the object. We do not discuss more on collision detection which is beyond the scope of this paper (see [MT94], [K93]).

The automatic grasping methodology is the following [MT94]: first a strategy is selected according to the type and the size of the object to grasp. A target location and orientation is determined for the hand frame and it is realized with the well known inverse kinematics approach. The next stage is to close the fingers according to the selected strategy (e.g. pinch, wrap, lateral, etc.) while sensor-object and sensor-sensor collisions are detected. Any touch detection locks the joints on the proximal side of the associated sensor. The grasping is completed when all the joints are locked or reaching their upper or lower limit.

3 Interactive Grasping with a Digital Glove

When an operator is wearing a digital glove the joint values acquired with the device are normally used to update the visualization of the hand posture. Such approach is pertinent as long as the device is used to specify commands through posture recognition [SZF89]. Among these commands there usually is a symbolic grasp of virtual objects where the relative position and orientation of the object is maintained fixed in the hand coordinate system as long as the grasp posture is recognized. Such approach is suitable for pick-and-place tasks of rigid objects and it is not our purpose to change it.

However, as the virtual environment is becoming more and more complex, especially with the advent of virtual humans, hand-based interactions also evolve in complexity. The limitation of the current approach mostly comes from the rough relative positioning of the hand and the object which does not convey a clear understanding of the action to perform with the object. As everybody has experienced him/herself, we adopt different grasping postures of a same object according to the function we intend to exert with that object because different degrees of mobility are involved for these different tasks (e.g. giving or using a screwdriver). Moreover, the immersion and the interaction in a virtual environment may not only reduce to a matter of pick and place but also imply abilities requiring a greater skill. In such a case the hand associated with the digital glove device provides a high dimensional space not only as a posture space (for command recognition) but also as a goal-oriented space (for precise manipulation or modification of virtual objects with additional tools). For example, interaction with non-manufactured deformable entities (articulated or continuously deformable objects) is best performed with direct hand interaction as it is our most elaborated tool to translate our design intention into action. in such context we need to evaluate precisely their mutual contact location.

3.1 Interactive Grasping Automata

Within this extended application context of the digital glove, it becomes crucial to display a posture of the hand consistent with the on-going manipulation of the virtual object. For this reason, we propose now a new approach for the interactive and consistent grasping of virtual entities with the interactive grasping automata (Figure 2).

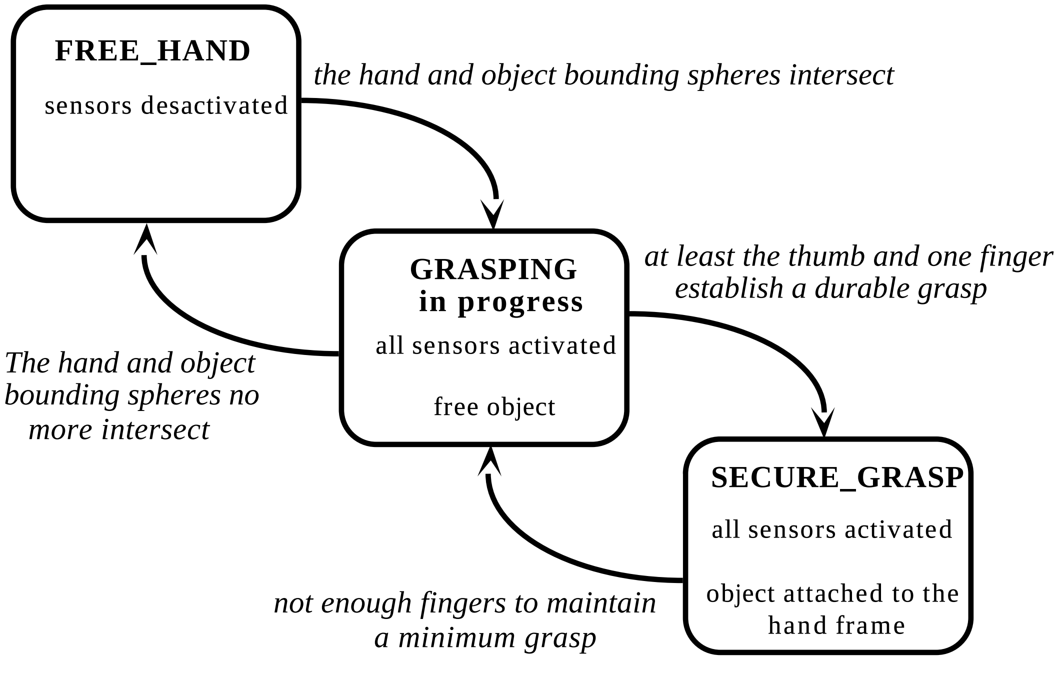

Figure 2 : The interactive grasping automata

In our method we consider three different states of interactive grasping :

FREE_HAND : the hand is freely moving in space without holding any object. The hand posture is displayed as measured with the device. Whenever the hand bounding sphere intersects the object bounding sphere, we enter in the "GRASPING in progress" state.

GRASPING in progress : the touch property of the sensors is continuously evaluated to adjust the posture of colliding fingers with the object to grasp (***the object is***

fixed or moving in a world coordinate system). Whenever the hand bounding sphere no more intersects the object bounding sphere, we return to the "FREE_HAND" state. On the other hand, if our simplified grasp condition is established, i.e. at least the thumb and one finger are maintaining a durable contact with the object, we enter the "SECURE_GRASP" state.

SECURE_GRASP : the touch property of the sensors is still used to continuously adjust the posture of colliding fingers with the grasped object (***the object position is fixed in the hand coordinate system***). As soon as the simplified grasp condition vanishes, we return to the "GRASPING in progress" state.

3.2 Hand Posture Correction

Unlike the automatic grasping procedure, the interactive grasping procedure adjusts the hand posture by opening it rather than closing it. Even with the recent generation of digital glove it is difficult to adjust the grasp precisely so that the fingers establish a permanent contact without penetrating into the virtual object. This is due to the fact that we only a have a visual feedback without any force or touch feedback. However, it would be misleading to conclude that the automatic grasping procedure should also apply in this context. Basically, interactive grasping implies to ensure the highest autonomy of the operator and to provide means of correction rather than removing degrees of freedom.

It is more comfortable for the operator to freely move and close the hand according to the visual feedback of the virtual environment. So our working hypothesis is to rely on the operator to permanently close the grasping fingers slightly more than theoretically necessary. In such a way, the opening correction approach establishes a durable contact which overcomes the unavoidable small variations of hand posture and position (Fig. 3). An optional mode of *Assisted Folding* is also provided to guide the operator in searching the proper grasp posture. In this mode, any sensor initially situated between the first colliding sensor and the finger tip is brought to be tangent to the object. If the sensor is intersecting the object then the associated joint is opened otherwise it is closed. In such a way, the distal part of a colliding finger consistently wraps around the object (Figure 4). The correction algorithm is characterized by an opening-wrapping adjustment loop with eventual Assisted Folding for each colliding finger. So, for each time step, we have :

```
For each colliding finger

      For each sensor distal to the colliding one closest to the base
            (from base side to tip side of the finger)

            If the sensor is currently colliding

                  Unfold the closest proximal joint (wrist side)
                     until the sensor is tangent to the object
                     or the joint reaches its limit

            Else

                  If in Assisted Folding Mode

                        Fold the closest proximal joint (wrist side)
                           until the sensor is tangent to the object
                           or the joint reaches its limit
                  EndIf
            EndIf
      EndFor
EndFor
```

Figure 3 details all the stages of the opening-wrapping algorithm for one colliding finger with an elliptic shape (in 2D for clarity). In the example, the joints are all successively opened because the distal sensors (on the finger tip side) are still colliding even after the correction of the proximal ones (on the wrist side). The algorithm begins by unfolding the finger base joint to release the first colliding sensor (fig. 3a,b). Then it unfolds the next joint to remove the following sensor (Fig 3b,c) and the same occurs for the last joint (Fig. 3c,d). In this case the final finger posture consistently wraps around the object.

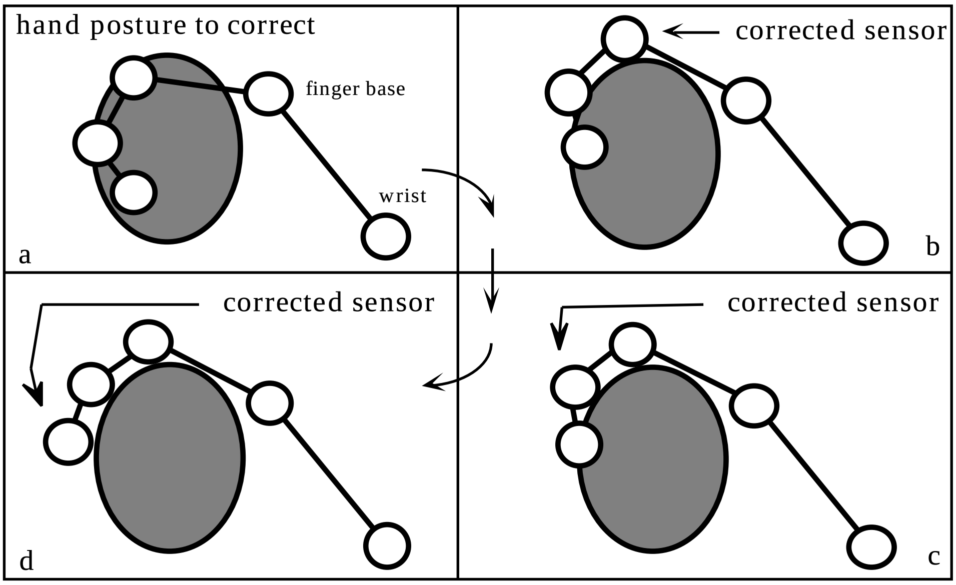

Figure 3 : an example of the opening-wrapping adjustment loop for interactive grasping

The Assisted Folding mode is especially interesting whenever the tip side of the finger is not in the operator field of view (Figure 4). This happens for a large class of grasping postures and objects to grasp. In such a way the operator is given a hint about the full grasp posture of the colliding fingers. Then, from that continuous visual feedback he/she can adjust the hand position, orientation and posture in order to perform a desired grasp. In figure 4 example, the first corrected sensor relies on opening the associated joint while the next two distal sensors are brought to be tangent to the rectangle shape by closing their associated joint.

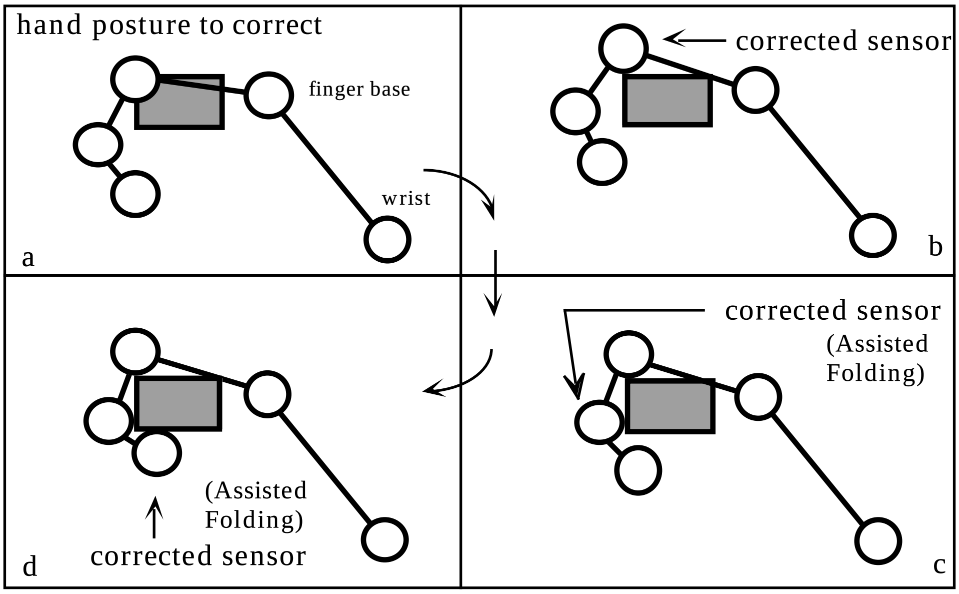

Figure 4 : an example of the opening-wrapping adjustment with assisted folding

4 Integration within the TRACK system

The TRACK animation system is dedicated to human animation design [BHMTT94]. More recently we have begun to evaluate the potential of virtual environments through 3D interaction with virtual humans. As such, both grasping approaches, automatic and interactive, are key features to integrate within the TRACK system. We now present the current state of this integration and outline the progressive intermixing of both techniques in order to allow complex grasping interaction.

- Automatic grasping of static volumic primitives and polygonal surfaces has been defined for both one and two hands grasping for the virtual human (Figure 1) [HBMTT95], [MT94]. So it is already possible to exchange handshake between virtual humans by activating their hand motion and automatic grasp in sequence rather than simultaneously.(figure 5).

- Autonomous interactive grasping is already performed on volumic primitives of the virtual environment and is to be extended on polygonal surface.

- Guiding one virtual human's hand with a 6D device as the Spaceball or a digital glove is an alternate approach to the knowledge-based selection of the grasp posture and positioning relatively to the object. The Automatic grasping closure is then performed to establish a wrapping grasp based on the sensor collision detection while closing the fingers. In such a context, the device must stay in the reachable area of the virtual human's hand otherwise the virtual human has to be globally displaced.

- Finally, the most complete intermixing of both techniques is to fully map the digital glove position and posture on the virtual human's hand and to manage it according to the interactive grasping approach. In such a way the operator can fully handle the grasping function of one virtual human model and interact with other virtual humans. The other virtual humans can in turn respond to the operator according to the automatic grasping approach as long as the grasping target is not moving. For moving objects as in a handshake context, the operator's virtual hand is the target of the virtual human's hand and both have to use the interactive grasp with assisted folding. In such a way the virtual human closes its fingers only when colliding the operator's hand. Moreover this requirement overcomes the operator's hand postural changes and simultaneous position variations.

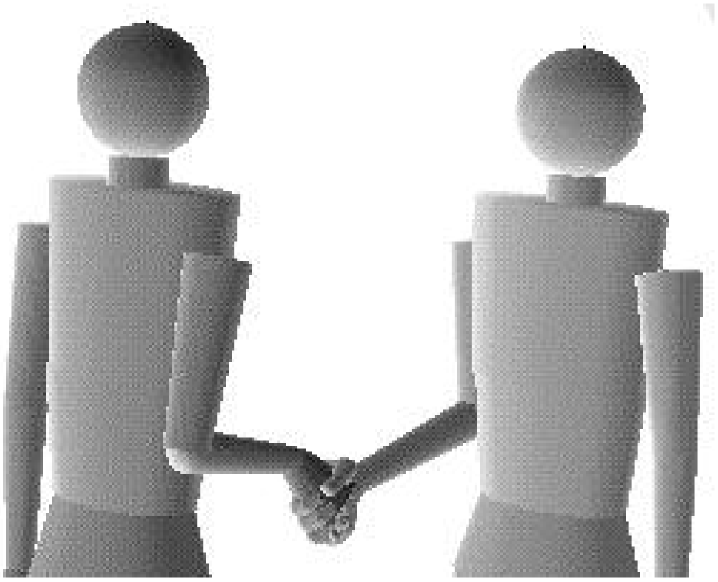

Figure 5.: handshake between virtual actors

5 Results

Three interactive grasping experiments are presented here. They deal with the grasping of regular volumic primitives as a sphere with various sizes. First figure 6 exhibits the hand model (as provided with the digital glove library from Virtual Technologies). We limit the size of the virtual objects to grasp in order to permit single hand grasping. Figure 7 shows simultaneous view of the real hand posture as acquired with the digital glove (on the right) and the one displayed as the result of the interactive grasping approach (on the left). The sensors are displayed as cubes to reduce the amount of polygons.

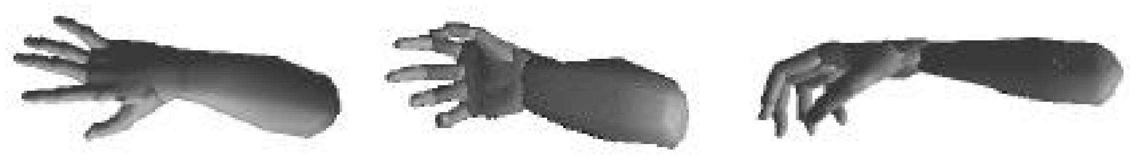

Figure 6 : hand model provided with the digital glove of Virtual Technologies

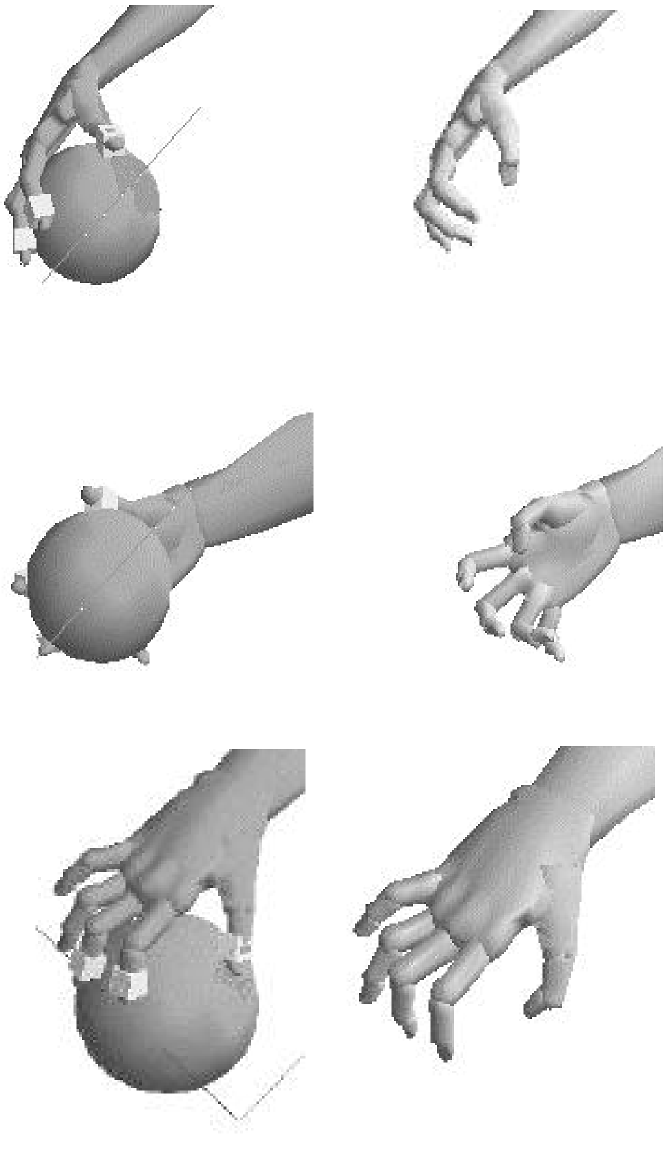

Figure 7 : the corrected (left) and the real (right) hand posture for various viewing angles, hand postures and object sizes (sphere primitives)

6 Discussion

The interactive grasping experiments were realized at interactive rate of approximately 10 images per second on a workstation screen with the management of up to 20 spherical sensors and the display of the high resolution hand (2600 polygons), the object and the sensors. Although a small delay was perceptible between performance and display of the corrected hand posture, is was not a decisive aspect.

Basically, interactive grasping proved to be a valuable tool for the interactive design of realistic grasping posture for human animation system. The interactive refresh rate is the main criteria for that purpose and our experiments have demonstrated this capability. So, from the visual feedback of the corrected grasp, an operator is able to achieve a good perception-action control loop in order to continuously adjust the grasp into a realistic posture. In our default setting the display is completed with color coding information as described now. Each state of the interactive grasping automata is associated with a different color of the whole hand : pale skin color for FREE_HAND, blue for GRASPING_in_progress and green for SECURE_GRASP. Moreover, whenever a sensor is colliding, its color changes from dark gray to light gray. This additional symbolic information significantly enhances the operator feedback.

Regarding Virtual Environments applications the realism of the grasping posture may not be an essential factor in favor of our approach. In such a context it is often not the point to behave exactly as in the real world. A VE operator is more concerned with a greater manipulation skill rather than a more realistic posture. In that aspect our approach also improves the manipulation of objects by comparison with the well known symbolic grasp. In the symbolic context, the operator has to perform well defined hand postures (at least two distinct ones) so that the recognition system separates properly the grasp from the release commands (not to mention that the object should be selected first). So, whenever the operator wishes to precisely modify the relative position and orientation of the object with respect to the hand (this is the proper definition of a manipulation), he/she has to grasp it, to reorient the hand-object system, release the reoriented object and move the hand freely to a new relative orientation. In our approach the reorientation is still performed in that way but the grasp is established in a much simpler way, just by touching the object with the thumb and another finger. Such procedure is much easier and faster that the one based on posture recognition.

As mentioned just before the finger manipulation skill is limited to set the begin and the end of the grasp. Modifying the relative orientation of the object with respect to the hand coordinate system is managed in the same way as symbolic grasping (see above). This procedure is tractable as long as we perform a light grasp involving a small number of fingers. Otherwise, the operator has to repeatedly close and open the hand which can be rapidly uncomfortable.

7 Implementation

We can either use the DataGlove from VPL or the Cyber Glove from Virtual Technologies. This latter has been retained for the performance evaluation all along the present experiments. The hand polygonal model provided by Virtual Technologies comes from the 3-D Dataset of Viewpoint DataLabs. The position and orientation of the Cyber Glove was acquired with one bird sensor from the "Flock of bird" device of Ascension Technologies. The interactive grasping was computed on a Silicon Graphics Indigo II Extreme. The virtual human and interactive grasping software are written in C language.

8 Conclusion

We have studied interactive grasping of virtual objects to improve the goal-oriented interactions of an operator wearing a digital glove device. The interactive grasping approach with the opening-wrapping algorithm ensures a consistent collision-free grasping of virtual objects which proves to be a valuable visual feedback for the operator hence allowing to manage tasks involving a higher skill than before. Encouraging performances on a standard graphic workstation open the way for integration in fully immersive systems.

Interesting applications of this techniques appear as virtual human models also begin to invade virtual environments or as the digital glove begin to invest animation systems dedicated to human animation design. For example, our approach can drive the grasp behavior of a virtual human model in order to simplify all the grasping studies for production. Both automatic and interactive grasping are integrated within our TRACK animation system.

9 Acknowledgments

We wish to thank our colleague Tom Molet for the implementation of the virtual human model in the framework of the ESPRIT project HUMANOID, and Ramon Mas who has developed the first version of the automatic grasping approach. The research was supported by the Swiss National Science Research Foundation and the Federal Office for Education and Science.

10 References

[BHMTT94] Boulic R., Huang Z., Magnenat-Thalmann N., Thalmann D. (1994) Goal-Oriented Design and Correction of Articulated Figure Motion with the TRACK System , Computer. & Graphics, Vol. 18, No. 4, pp. 443-452.

[EB85] Espiau B., Boulic R. (1985) Collision avoidance for redundant robots with proximity sensors, Proc. of Third International Symposium of Robotics Research, Gouvieux, October.

[HBMTT95] Huang Z., Boulic R., Magnenat-Thalmann N., Thalmann D "A Multi-sensor Approach for Grasping and 3D Interaction" , Proc. of CGI 95, Leeds

[K93] Kamat V.V. (1993) A Survey of Techniques for Simulation of Dynamic Collision Detection and Response, Computers & Graphics, Vol 17(4)

[L93] Lee P.L.Y. (1993) Modeling Articulated Figure Motion with Physically- and Physiologically-based Constraints, Ph.D. Dissertation in Mechanical Engineering and Applied Mechanics, University of Pennsylvania.

[MT94] Mas R., Thalmann D. (1994) A Hand Control and Automatic Grasping System for Synthetic Actors, Proceedings of Eurographic'94, pp.167-178.

[PB90] Philips C. B., Zhao J., Badler N. I. (1990) Interactive Real-Time Articulated Figure Manipulation Using Multiple Kinematic Constraints, Computer Graphics 24 (2), pp.245-250.

[RG91] Rijpkema H and Girard M. (1991) Computer animation of knowledge-based human grasping, Proceedings of Siggraph'91, pp.339-348.

[SZF89] Sturman D.J., Zeltzer D., Feiner S.(1989) Hands-on Interaction with Virtual Environments, Proc. of ACM SIGGRAPH Symposium on User Interface Software and Technologies, pp 19-24

[vdPF93] van de Panne M., Fiume E. (1993) Sensor-Actuator Network, Computer Graphics, Annual Conference Series, 1993, pp.335-342.