

Stretch 'n' Cut: Method for Observing and Ungrouping Complex Virtual Objects in 3D Space Using Elastic Band Metaphor

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ABSTRACT

We propose a system which realizes gesture-based separation, and the observation of a group of parts from complex virtual objects in 3D space. One practical application of our system is for training purposes such as learning the structures of complex 3D object such as the human body or industrial products. By using an “elastic band” metaphor, our method enables users to (1) observe the relationship (connection and its strength) between the parts and (2) separate a part of the object efficiently.

Keywords: Virtual reality, augmented reality, mixed reality, ungrouping and observation, gesture, audio-visual feedback, elastic, manipulation.

Index Terms: H5.2 [Information interfaces and presentation]: User Interfaces - Auditory (non-speech) feedback, Interaction styles, Input devices and strategies; H5.1 [Information interfaces and presentation]: Multimedia Information Systems - Artificial, augmented, and virtual realities.

1 INTRODUCTION

Today’s technology enables users to manipulate complex, multi-part 3D virtual objects such as industrial products, structures designed by CAD, and models of the human body in large 3D space [5]. One of the applications is its use in training and education, such as for learning the structure of human body or industrial products. We have previously proposed a method by which users can ungroup and observe a complex virtual object that was grouped beforehand in a 3D mixed reality (MR) space into small parts using a gesture operation to learn the structure [9]. The method avoided incorrect operations and improved the operational feel by setting a detachment condition for separating the parts of an object, and provided audio-visual feedback to users using the real-world “elastic band” metaphor.

However, in the previous study, we focused on the feedbacks, rather than the ungroup operation. The group of parts that can be ungrouped by the user had been predefined. In this research, we realized a more flexible ungroup process using this metaphor.

Figure 1 shows an example of our method. When the user lifts up a given part, the connected parts are also lifted up gradually, depending on the extent of the hand movement. (i) The user can observe in detail the connections and the strength of the connections between the parts by the visual feedback of a virtual elastic band that expands and contracts. (ii) The user can separate the group of parts freely by using the other hand to cut those that connect to unnecessary parts and observe the connections.

2 RELATED WORK

Several techniques have been proposed to enable the observation of complex objects that display the inner parts [3][14]. Because these methods remove the outer parts, the user cannot observe the back portion of the outer parts, and the connections to the inner parts. In contrast, in our method, the user can observe both by lifting up and looking into the outer parts (Advantage 1).

Li *et al.* [6] proposed a method that is based on the explosion

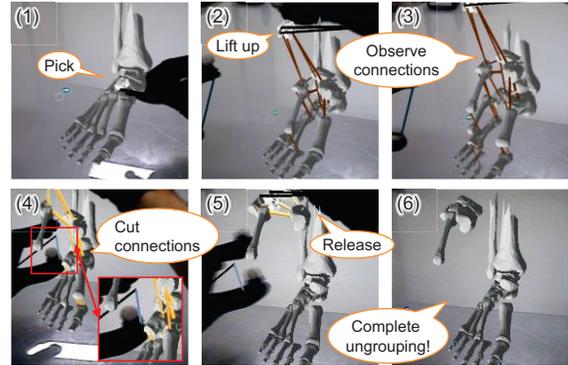


Figure 1: Observing and ungrouping by proposed method.

diagram, which automatically separates the outer parts depending on the selected parts. Our method shows connections clearly using the virtual elastic band (Advantage 2). In addition, by changing the appearance of the elastic band, it can provide the connection strength between the parts (e.g. screwed or glued) (Advantage 3).

There are various selection techniques, because of a fundamental operation [1]. To select multiple objects that we aim to realize, some techniques are similar to traditional selection techniques for 2D applications such as using a rectangle, circle, or lasso tool [10][11]. Those enable the user to simultaneously select multiple 3D objects. However, since the selection area is 2D, the selection of the depth is uncertain. In case of using a 3D selection volume such as a frustum [12] or a cuboid [4][8], though the user can select the target considering the depth, because of the simple shape, it is hard to avoid selecting unnecessary parts. Methods wherein the group of parts that moves together [15][7] are proposed using either the positional relationship of the parts or the moving direction of the selected parts. However, in the case where both the unnecessary and necessary parts are moving in the direction of the selected parts, it is difficult to select only the necessary parts.

If the user uses either of the above methods multiple times then the selection and ungrouping is possible; however, the operation becomes cumbersome. On the other hand, in the proposed method, because the user can separate the group of parts freely by cutting their connections to unnecessary parts, it is possible to realize a flexible ungrouping (Advantage 4).

3 PROPOSED METHOD

3.1 Selecting The Parts That Are Shown As Expanded Parts

In this study, the contact relationships of each part are used as a graph (Figure 2).

For ungrouping, firstly, the user lifts up a part and expands some parts. To avoid the users lose the original shape of the object and target parts, the expansion takes place gradually depending on the distance of the user’s hand moving length from the position at which the part was picked up to the current position l_{arm} (Figure 2), based on Shiozawa’s method [13].

In our method, using a graph traversal, the system first calculates the distance on the graph from the part, which is to be

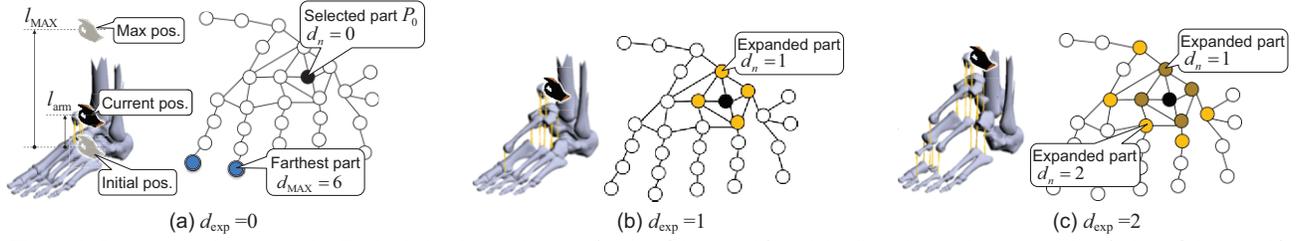


Figure 2: Part expansion example. Each circle shows the part (node of the graph) and the line shows the connection (edge of the graph)

picked up by the user (P_0) to each of the other parts (P_n , $0 < n \leq k$, where k is the total number of parts, excluding P_0). Next the range of expansion d_{exp} ($0 \leq d_{exp} \leq d_{MAX}$) is calculated using l_{arm} , and subsequently all of the parts, which are $d_n \leq d_{exp}$. Each time that the user changes the parts that are picked up, the system calculates the distance to the furthest part on the graph d_{MAX} . The system enables the user to expand all of the parts within the possible range of the user's hand movement, i.e., the movement length is shorter than the maximum movement length l_{MAX} , which is measured in advance. d_{exp} is given as follows:

$$d_{exp} = \begin{cases} d_{MAX} \frac{l_{arm}}{l_{MAX}} & (0 \leq l_{arm} \leq l_{MAX}) \\ d_{MAX} & (l_{MAX} < l_{arm}) \end{cases} \quad (1)$$

To prevent the entire object from moving because of the pulling of the parts, we set the part that has only one edge on the graph as the anchor part as "anchor part," which is fixed at the initial position, and which is not expanded regardless of d_n .

3.2 Displaying Expanded Parts

The left figures in Figure 2 (a)-(c) show the visual feedback (virtual elastic bands) between the parts. The direction of the expansion of the parts is the same as that of the user's hand movement, therefore, some of the parts would not expand and thus the user is unable to observe and cut the virtual elastic band. To ensure that there is space between all parts, we implemented a force-based algorithm [2] using the elastic F_{ela} and the repulsive force F_{rep} to calculate the behavior of the parts (Figure 3). F_{ela} is given by the following equation using coefficient k_{ela} , and the distance between the contact surfaces of parts l_{sur} .

$$F_{ela} = k_{ela} l_{sur} \quad (2)$$

After cutting the elastic band, the elastic force becomes 0. Because the force-based algorithm uses only the distance from the center of the part to calculate the repulsive force, therefore, it is necessary to consider the size of the part. The repulsive force F_{rep} is given by the following equation using the coefficient k_{rep} ; distance between the center of the parts l_{cen} ; and size of bounding box of parts B_1 and B_2 .

$$F_{rep} = k_{rep} \frac{\log(B_1 + B_2)}{l_{cen}} \quad (3)$$

In the case of a more complex virtual object and a larger number of parts, the space between the parts may not be enough. To address this issue, we implemented a "local expansion function." Here, the user can expand the parts locally by moving the effective area which appears at the position of the user's other hand. This changes the elastic and repulsive forces acting on the parts in the effective area. If the user moves the hand closer to the parts then the elastic force becomes smaller and the repulsive force becomes larger, as a result, the space between the parts becomes larger.

3.3 Displaying The Relationships

In the proposed method, the virtual elastic band, which is shown by lifting up the part, shows the relationship between the parts.

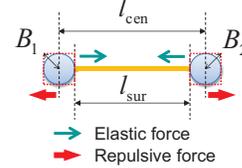


Figure 3: Force-based algorithm [2].

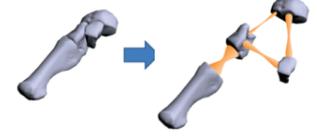


Figure 4: Displaying the connection strength between parts using the width of the elastic band.

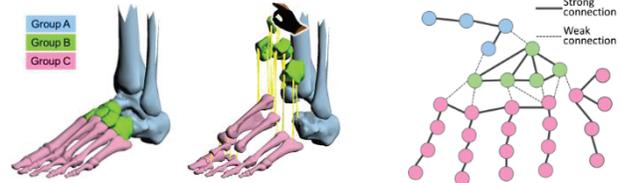


Figure 5: Displaying group relationships. (In this figure, groups are color coded for ease of understanding)

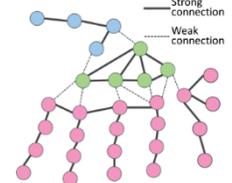


Figure 6: Setting of the connection strength and group.

In Figure 4, with or without the elastic band show the connection from the part to part and the start and end of the band show the points of connection. The width of the band shows the strength of the physical connection (e.g., the part that is attached using a thick screw is a strong connection). The semantic connection strength depends on the group and is shown by making a cluster of the same group (Figure 5). To realize this, the group is set in advance when the modeler makes a 3D model. In the case that parts are in the same group, the elastic force between the parts is set as strong (Figure 6). In our system, the user is allowed to switch this function when desired.

3.4 Ungrouping The Parts

By cutting the virtual elastic bands connected to unnecessary parts, the user can ungroup the target group of parts. In our system, the user can cut the expanded band by crossing hands; repeating the cutting; and ungrouping. After all of the parts of the object are separated into two or more groups, if the user releases the lifted part then the ungrouping operation will be completed. Before the separation, if the user releases the lifted part then all of the expanded parts return to the initial position because of the elastic force, and the cutting can be undone instantly.

The user can also use the local expanding function together; thus, the user can simultaneously expand the space between the parts locally, while cutting the elastic band using the function.

4 IMPLEMENTATION

We developed a MR system with gesture operation (Figure 7) that uses the proposed methods. Users view the MR space through a video-see-through head-mounted display (HMD, Canon VH-2002). To generate the MR space, two real-world input images are captured from the HMD cameras through a video capture card (ViewCast Osprey-440) on the PC for managing MR space

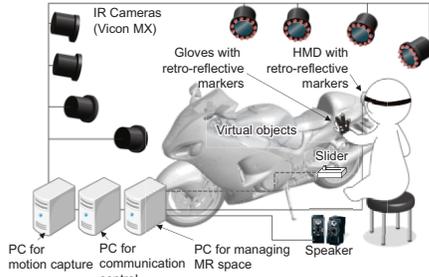
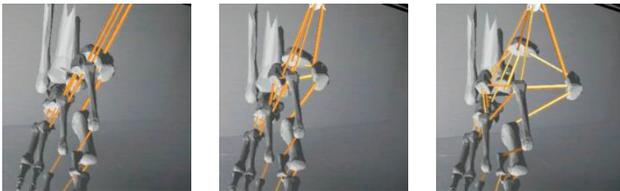


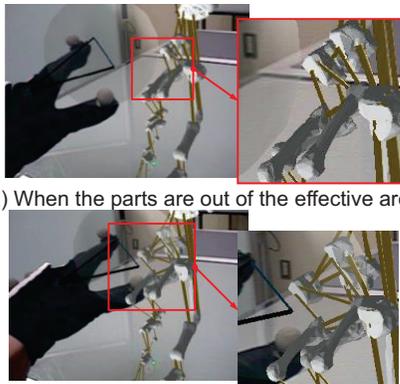
Figure 7: System configuration.



(a) picking up P_0 (b) $d_n = 0$ (c) $d_n = 1$
 Figure 8: The number of expanding parts increased depending on the moving distance of the hand ($k_{rep} = 0$).

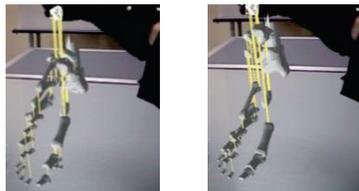


(a) $k_{rep} = 0$ (b) $k_{rep} = 60$ (d) $k_{rep} = 200$
 Figure 9: By increasing the repulsive force, the space between the parts becomes wider.



(a) When the parts are out of the effective area.

(b) When the parts are in the effective area they expand fully.
 Figure 10: Expanding the parts locally



(a) default (b) gather the group
 Figure 11: Difference in representation of groups.

(Windows7 OS, Intel Core i7 965 EE 3.20 GHz CPU, 6G RAM). Next, the images are generated in real time using the HMD's position and orientation. The images are superimposed onto the real-world images. Then, the two output images from a graphics card (NVIDIA Quadro FX 1700) are displayed to the

user by each HMD display. Hand gestures are detected by a ViconPeaks motion capture system. It uses infrared technology to enable tracking of finger positions, and the position and orientation of the HMD.

The following auditory feedback sounds were played through a speaker when the user lifts up the part: "Streeeeetch", releases the part: "Swish!", cuts the virtual elastic band: "Snap!", in addition, the part returns to the initial position and collides with another part that is connected to "Click." Because each user's preference may differ, we implemented the physical slider to adjust the strength of the repulsive force. The value from the variable resistance via Funnel I/O (SparkFun Electronics) is sent wirelessly to the PC for MR space management via XBee (Digi International).

Figure 8 shows the gradual expansion of the parts using the foot bone model. Figure 9 shows the expansion according to different repulsion forces. Figure 10 shows the expansion of the parts locally. The distance between the parts in the effective area becomes larger as the user moves the hand closer to the part. Figure 11 shows the difference in the representation of the groups using expansion and contraction. Figure 1 (4)-(6) shows the ungrouping process by the cutting of the virtual elastic band connections.

5 EVALUATION

We evaluated the four features of our technique; *Expanding gradually and cutting the connection*, *Adjusting repulsive force*, *Local expansion*, and *Group expansion*, by comparing it with the condition without the functions using virtual foot bone model (Parts# 30, edge# 35). All of the parts were grouped and named. When a subject expanded the parts, the parts and group name were shown as a .label. Eight subjects in their 20s were seated while performing tasks, but were allowed to freely move their heads. They practiced the operation using the model (Figure 12). During the experiment, the operations were recorded.

We asked the subjects to perform the observation and ungrouping tasks using two different conditions. After completion of each experiment, the subjects evaluated the trial on a five-point scale from 1 to 5. (1: Condition 1 is useful, 5: Condition 2 is useful).

In experiment 1-3, the observation task required the subject to identify by names all of the parts that were connected to the target part. The ungroup task involved ungrouping the target part. In experiment 4, the observation task involved identifying the number of parts that belong to the target group. The ungroup task then involved ungrouping the target group.

Table 1 shows the conditions in each experiment. All of the subjects performed tasks from experiment 1 to 4, and the order of the conditions was changed for each subject. In every experiment, Condition 2 was the case using the features of our proposed method.

The target parts and groups were decided in advance via a pilot test, and there were no trials that used the same target part/group.

Figure 13 shows the result of the five-point scale evaluation. Our proposed method received high ratings in all experiments.

Expanding and Cutting: Since the users could adjust the level of expansion, and move the position of the parts freely, they felt that observations and ungroup were easier. In addition, they could avoid losing the target part, they could cut the connections easily and accurately.

Adjusting Repulsive Force: For both of the observation and ungroup, the subjects commented that the function was useful, because they can make precise adjustments to the values when desired. The user's operation logs supported this, the values of the repulsive force and the speeds of manipulating the slider were different for each subject and each task.

Local Expansion: In the observation task, since the subjects can

focus on where they were needed, they preferred this function. As mentioned in Section 3.4, we assumed that the user can use this function to cut the elastic band during expansion. Half of the subjects commented that it simplified the ungrouping. However, during the observation task, because they cut the elastic band accidentally, the score became lower. To solve this problem, a trigger for switching this function ON/OFF is needed.

Group Expansion: All of the subjects commented that this function definitely simplified the observation and ungroup.

6 APPLICATION TO OTHER 3D MODELS

Figure 14 shows an example where the proposed method is applied to other virtual objects. Table 2 shows the number of parts, edges, and polygons, and Processing speed (FPS).

Processing speed: This depends on the number of polygons. Although the number of parts and edges increase, if the number of polygons is less than approx. 60,000 then there is no delay.

Expanding the parts: Even in the case where there are many thin and small parts (such as microscope model), we can expand and observe them by picking up the larger parts that are connected to those thin and small parts.

Observation and ungrouping: This was more difficult in the case using a microscope and track model than the case the using foot bone model, because there were more anchor parts and they were dense. Moreover, because of the steric structure, the space is limited, and many parts and edges overlap with each other. Furthermore, because the part sizes were large, and the distance between edges was far, the lung and heart model had comparatively few problems. Therefore, we implemented a function that allowed the user to move the anchor parts and some other parts individually before expanding with the other hand. Although in our implementation, in our future work, we plan to implement the function to enable the anchor parts to be changed.

7 CONCLUSION

In this study, we proposed a method that enables users to observe and ungroup complex 3D virtual objects using gesture manipulation. By using the virtual elastic band, the system can (i) present the physical and semantic relationships between the parts, allowing users to observe the complex object in detail, and (ii) ungroup the group of the desired parts by cutting the bands. The result of our user study showed that the proposed method is effective. Furthermore, we applied the method to some other models, and discussed the limitations and solutions. Although this method was realized in MR, it can be applied to operation in virtual reality and ordinal CAD systems using mouse and multi-touch display. For future work, we plan to apply such systems to other applications, compare the difference between the system configurations, and improve the method for each configuration.

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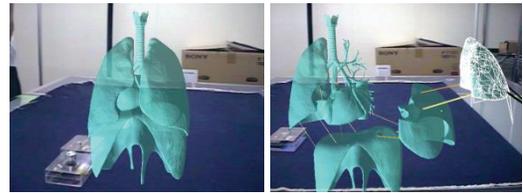


Figure 12: Lung and heart model for practice

Table 1: Experimental conditions. (* Manu. = Manually)

Experiment #	1		2		3		4	
Condition #	1	2	1	2	1	2	1	2
Func.	Expanding & Cutting	Auto	Manu.	Manu.	Manu.	Manu.	Manu.	Manu.
	Adjusting repulsive force	OFF	OFF	OFF	Manu.	OFF	OFF	OFF
	Local expansion	OFF	OFF	OFF	OFF	OFF	Manu.	OFF
	Group expansion	OFF	OFF	OFF	OFF	OFF	OFF	Manu.

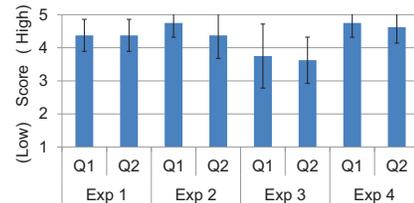


Figure 13: Experiment results:

Average of five point scale evaluation and standard deviation.



(a) Truck

(b) Microscope

Figure 14 Test cases

Table 2: Parts, edge, polygon numbers, and average FPS of each virtual object.

	Parts #	Edge #	Polygon #	Ave. FPS
Foot bone	30	35	15276	54.6
Microscope	34	35	7984	57.5
Truck	29	29	62958	32.7
Lung and heart	12	13	279859	9.0

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