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Editing Recorded Haptic Data with SiRE – Simulation Record Editor

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ABSTRACT

This paper presents editing of recorded haptic data with SiRE – Simulation Record Editor. SiRE offers the possibility of authoring perfect surgical examples and rapid production of variations. Edited haptic data is intended to be used as a self-learning aid to medical residents. SiRE enables definition of segments of manipulation through a visual 3D playback. For editing of haptic data, three methods are proposed. Each of the methods has its advantages and disadvantages, but together they allow flexible and accurate editing of haptic data matching to the user's needs.

Keywords: haptic, surgical simulation, skill-transfer, authoring

1 INTRODUCTION

Many research groups are working to increase realism of surgical simulation consisting of visual, haptic and audio feedback. Recently, research on methods that promote the use of simulators in surgical training has increased. Modeling of surgical procedures and evaluation of surgical skill [1,2,3,4] have become an important target for research. This paper continues the exploration by discussing the use of edited haptic data as example surgical manipulation.

In the research of haptics, record-and-play strategy has been investigated and found beneficial in teaching of tasks such as hand-writing [5,6]. A similar approach is preferred in medicine for acceleration of skill-transfer. However, the medical domain has introduced challenges of complex manipulation and need for deep understanding of surgical procedures. Use of annotation in the simulation system would meet the students' needs derived from the complexity [7]. Immersive Electronic Books [8] are an example of annotation in surgical training, but the system does not support haptic feedback, which is an essential part of training of manipulation with surgical simulators. The authors are developing a framework for surgical skill-transfer based on record-and-play strategy and annotation of manipulation. A critical part of surgical training is to gain experience in variations of a standard text-book case. Several surgical simulators have addressed the challenge of variation by providing modifiability of anatomy and interaction models for simulation with relatively small effort [9,10]. This study aims to support variation of recorded example manipulation by editing existing Simulation Records (SR) and also highlights the need for perfect example manipulation.

Here, two cases applicable to the context of surgical training are presented: making of variations and perfect examples. Since recorded manipulation is digital data, the mistakes in the original recorded manipulation can be corrected digitally. This enables a teaching surgeon to record the manipulation on a surgical simulator and to fine-tune the recorded example afterwards without full focus on the performance. It would be beneficial for the use of recorded simulation in surgical training, if another person could edit the surgeon's manipulation. For making variations and perfecting examples of surgical manipulation, the following requirements of the editing methods were determined:

- Replacement of total failures in the original manipulation.
- Making variations by replacing selected sections of the original manipulation.
- Correction of very small mistakes with high accuracy.
- The need for true manipulation skill should be minimized, so that another person than a surgeon could be responsible for the editing.

2 METHODOLOGY

2.1 Data Model for Recorded Simulation

SiRE's data model consists of two layers: raw input data and visual playback medium. Unlike the typical skill-transfer systems that focus on writing with a pen, the surgical field requires recording of the changes in the target in addition to the user's actions. The two layers constitute a SR which covers the user's manipulation and a visual playback. Figure 1 illustrates the dual nature of a SR. The simulation environment for the SR is assumed to be a mesh-based 3D model that is manipulated using a haptic device.

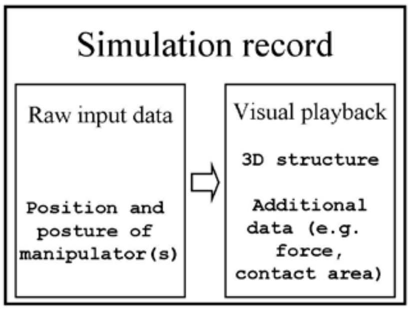

Figure 1 : *The two data layers of a SR used in SiRE. All data is time series.*

Raw input data is a complete record of the user's input to the simulator. In a typical desktop simulation setup including a haptic device, the raw input data covers position and posture of the manipulator(s). The input data is recorded at the best possible accuracy of the simulation, which enables re-simulation by feeding the input data back to the simulation engine. During re-simulation, without any feedback to the user, the visual playback is computed from the input data.

The playback consists of time series of 3D structure of the anatomy model. Deformable organs are usually represented in

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surgical simulation as 3D meshes with changeable location of its vertices. In practice, time series of 3D structure is displacement of the vertices sampled at a chosen frame-rate. Playback by feeding new positions to vertices is a very light process compared to running the simulation. In addition, each frame of the 3D structure time series is autonomic, so that any frame can be selected at any time. This allows for flexible playback that can be skimmed easily.

The playback part of the SR can store any additional data needed for self-learning from recorded simulation. For example, force data and contact area can be stored and shown in the playback as additional visualization aid to the user.

2.2 Editing of Recorded Haptic Data

Figure 2 presents two cases of editing recorded haptic data: perfecting examples and making variations. Perfection covers replacement of original segments with the edited ones. Variations are produced by duplicating some of the original segments whereas the segment that introduces new manipulation is edited.

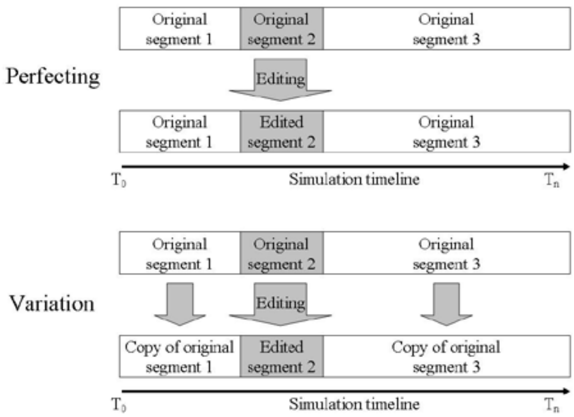

Figure 2 : *Concept of editing a SR toward perfect or alternative manipulation.*

Editing process is explained in Figure 3. First, a segment to be edited is sought by browsing the visual playback. Then, the segment's start and end positions are determined. Lastly, the segment is edited by one of the three methods explained below.

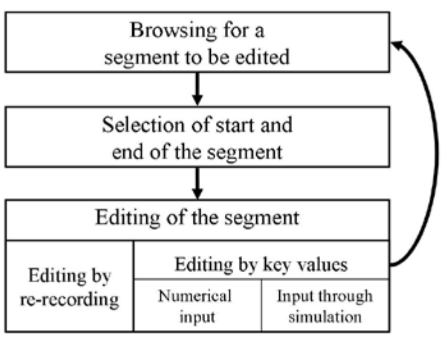

Figure 3 : *Process cycle for editing.*

2.2.1 Re-recording

Re-recording is a straight-forward editing method. The original segment is replaced by the user's interaction with the simulation starting from the segment's start point. New manipulation is recorded normally during the simulation. Any differences between the start and end points in the original manipulation and the new manipulation are interpolated to maintain continuity of the manipulation. The re-recording method allows correction of mistakes and making of very different variations, but requires user's manipulation skill.

2.2.2 Editing by Key Values

This method enables a person other than the recording surgeon to edit manipulation and provides better accuracy than re-recording. The user is required to input a key value by which the original manipulation is processed numerically. Because of the numerical processing, this method does not require manipulation skill, yet, it allows accurate editing. Figure 4 illustrates how a segment of original trajectory is selected and edited by giving a new contact location. The trajectory within the segment's borders, being a time series of position data, is processed to pass through the new contact location.

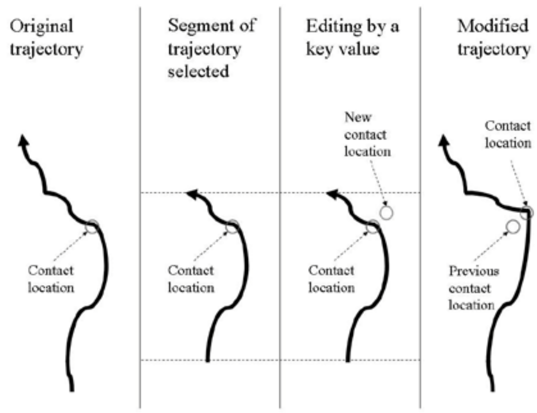

Figure 4 : *Editing by setting a key value to indicate a new contact location. The trajectory in the selected segment is computed to pass through the user-given location.*

To input the key values there are two user-interface solutions: input through interactive simulation and numerical input. Using the interactive simulation, the user is given the control of the simulation. Instead of recording the whole manipulation, only one state of the user's manipulation is recorded. The recorded state acts as a new key value. Using this editing mode, the user can perceive the desired state of the simulation.

Numerical editing provides the best accuracy for the key values but does not allow for interaction with the simulation. The user interface is equipped with editable numerical information about the simulated manipulation, such as position of the manipulator and reaction force perceivable to the user. Numerical editing allows editing operations such as

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accurate normalization of similar repetitive manipulation and is best suitable for high accuracy fine-tuning.

2.2.3 Numerical Processing of Trajectories

Editing direction for individual pushing movements that are frequently used in surgical manipulation, such as palpation, is determined in either of two approaches shown in Figure 5. The algorithm can be applied also in cases where the user cannot give the key value as a simple position. For example, power computed in the simulation can be used as the key value. In the case shown in Figure 5a), a tangent vector is formed of the first and the last collision points (p_{col1} and p_{col2}). The tangent vector determines the direction. In order to reach a user-given power value, pre-simulation is executed so that a temporary manipulator position proceeds along the tangent vector until the user-given power is met at p_c. The vector reaching pc is calculated by a cross product from p_{col1} and p_{col2}. The target position p_t is calculated from the difference of distance to the tangent vector from p_c and p_n.

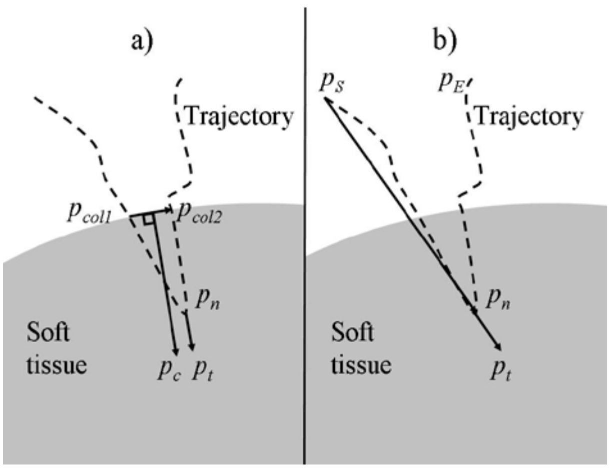

Figure 5 : *Strategies for determining suitable directions for key value –based editing: a) directly against the target soft tissue model by using collision information, or b) by user-defined start of the editable segment.*

Algorithm used for lengthening or shortening a trajectory is described in Figure 6. Properties of manipulation that are essential in the surgical context have to be taken into account in the choice of algorithm. In the surgical context, for example smoothness [11] and velocity of the trajectory can indicate the manual skill of a surgeon. Therefore, when lengthening sampled position time-series, additional points have to be added when the target point (p_t) is further than the trajectory's furthest point (p_n). Consequently, points have to be deleted when the trajectory should be shortened. The trajectory is divided in two from p_t so that both parts are computed separately to approach p_n. (1) is executed until the remaining distance to the target point becomes smaller than the distance added. (2) is used only for the last addition, and it is the only modification that affects the average velocity.

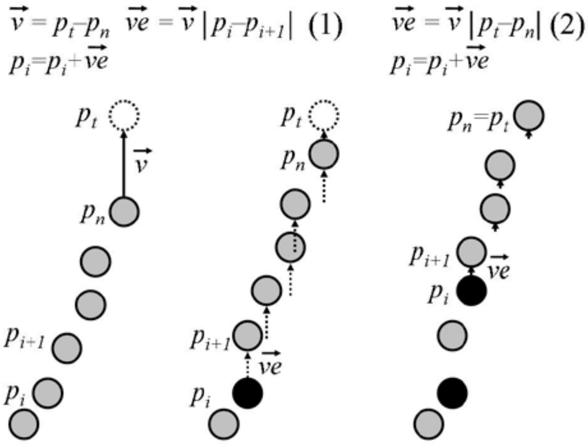

Figure 6 : *Algorithm used for lengthening trajectory data. Points are added to maintain smoothness and average velocity of the trajectory. The trajectory is shortened by removing points.*

2.2.4 Use of the Editing Methods

Table 1 summarizes advantages, disadvantages and the best uses of the three editing methods. Each of the methods has its use. Accurate and easy editing of recorded haptic data is achieved by using all the methods in suitable combinations, such as re-recording followed by key value –based editing in order to make the manipulation match with well-known figures.

Table 1 : *Summary of the editing methods.*

Editing method	Advantage	Disadvantage	Use
Re-recording	Allows complete deletion of mistakes, interactive simulation	Requires true manipulation skill	Correction of complete mistakes, recording of alternative approaches
Editing key values through interactive simulation	Fast and accurate, interactive simulation	Requires accurate manipulation momentarily, limited options for making variations	Adjustment of little mistakes, alternative approaches by using the original manipulation
Numerical editing of key values	Does not require any manipulation skill, highly accurate	Slow, numerical data is hard to comprehend, no interactive simulation	Fine-tuning for perfect accuracy

3 EXPERIMENT

The experiment focused on validation of the numerical processing of the trajectory data in terms smoothness, which is an important indicator of surgical skill. If the smoothness remained as in the original manipulation, the trajectory

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processing method can be used without losing essential data and important properties of the manipulation.

SiRE was implemented onto the Medical Virtual reality simulation Library (MVL) [10]. MVL contains computational methods and various organ models that allow rapid development of new simulation scenes in C++. Realistic modeling of interaction with soft tissues is achieved by using Finite Element Method -based algorithms. Visual feedback is implemented with OpenGL libraries. The system runs on a Xeon 3.2 GHz dual processor with 4 GB RAM and the haptic feedback is given through SensAble's PHANTOM® Desktop™.

Manipulation was recorded at 1000 Hz in a palpation of the aorta simulation with a peak power of 0.79 N. The trajectory was processed by inputting key values numerically at a constant +0.1 N interval up to 1.99 N (see section 2.2.3) and compared to the original manipulation's smoothness by time-integrated squared jerk metrics [11].

4 RESULTS

Figure 7 shows the results of the experiment. Smoothness remained about constant. Slight variation resulted from using (2) for the addition of the last point to the trajectory.

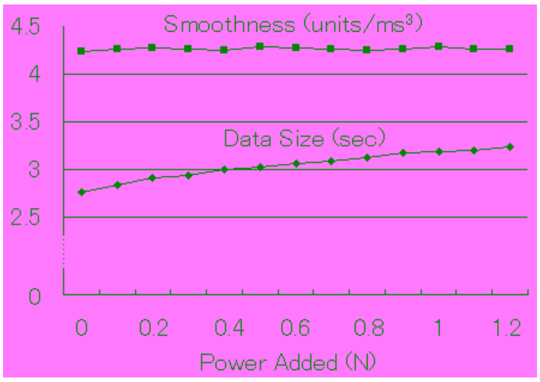

Figure 7 : *Validation of smoothness of an edited trajectory. Smoothness remained at about 4.25 units/ms^3 even though the data size increased.*

Figure 8 demonstrates how the trajectory's shape was preserved. The edited trajectory used in the experiment is shown against the edited versions. The strategy explained in Figure 5b) was used to determine the direction of the lengthening procedure.

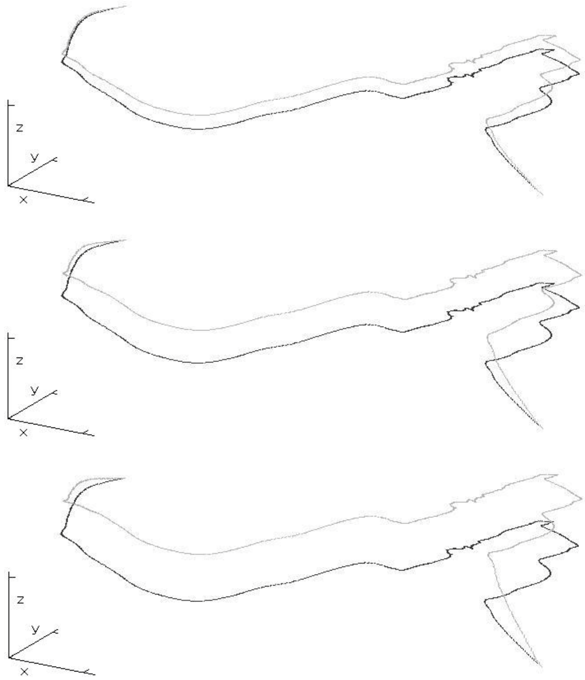

Figure 8 : *The original trajectory (black) vs. the edited trajectories (grey). Top: trajectory edited by giving a key value of +0.1 N. Middle: edited by +0.2 N. Bottom: edited by +0.3 N.*

5 CONCLUSION

This paper presented methods for editing of haptic data in two cases: making of variations and perfect examples. The methods aimed to facilitate editing of past manipulation so that large mistakes as well as small errors could be corrected. New manipulation or reused original manipulation had to be edited into the SR with an easy-to-use manner, so that editing could be done by a person without true manipulation skill. Three methods for editing were designed, developed and their uses analyzed:

1. Re-recording is suitable for correcting of complete mistakes and recording of variations very different to the original manipulation.
2. Editing key values through interactive simulation matches to the need of quick adjustments and reuse of the original manipulation for slightly different variations.
3. Numerical editing of key values, the most accurate but also the slowest method, is suitable for fine-tuning for perfectly accurate manipulation.

To give an impression on how editing of SRs can be carried out in practice, Figure 9 includes screen capture images showing how to correct a mistake in recorded simulation. Excessive power in a past palpation of the aorta procedure is reduced by feeling the correct power level through the simulator's force feedback features and by clicking a button that triggers processing of the trajectory data.

Within this study, only the trajectory processing by user-given key values was implemented and evaluated using

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criteria relevant to the surgical context. Future studies will evaluate the validity of the re-recording approach and user comfort.

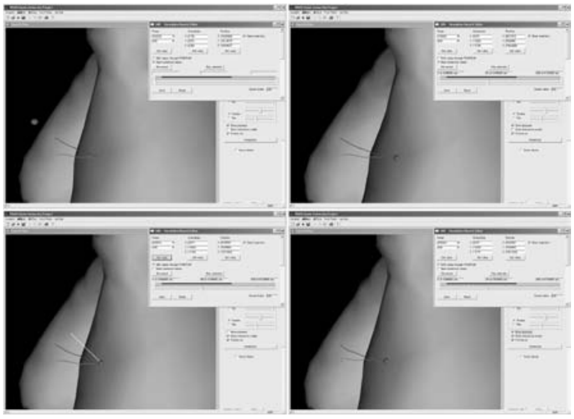

Figure 9 : *Recorded palpation of the aorta is being perfected by reducing peak power from 1.54 N to about 0.5 N.* ***Top left:*** *A segment is selected for editing and trajectory visualized.* ***Top right:*** *Situation at the power's peak.* ***Bottom left:*** *Setting a new key value by feeling the power through force feedback (the white line indicates reaction force).* ***Bottom right:*** *The result.*

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