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A Novel Approach for Training of Surgical Procedures Based on Visualization and Annotation of Behavioural Parameters in Simulators

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Abstract. Recording performance during training sessions on simulators is becoming a new standard for assessment of surgical skills and thus a significant part of training. Typical simulator-based training can be assessed using criteria that cover the whole procedure to make distinction between skill levels. Studies so far have rarely addressed the challenge of how to provide better feedback about the user's performance on a surgical simulator. Our approach for surgical training is Annotated Simulation Records (ASRs) and visualization of behavioural parameters of interaction in surgery. This paper briefly outlines a framework for building user-defined skill models and presents initial results. We demonstrate the ASR-based approach in force exertion tasks on elastic objects by utilizing a cardiovascular surgeon's recorded interaction on an aorta palpation simulator.

Keywords. Annotation, skill modelling, skill training, haptic

Introduction

Recording performance during training sessions on simulators is becoming the new standard for assessment of surgical skills and thus a significant part of training. Studies have shown how simulator-based training can be assessed using criteria that can make a distinction between skill levels, for example motion analysis of laparoscopic tools [1]. Considering that metrics should be procedure-specific [2], the general metrics in simulators have limited use. Motion analysis does not cover other relevant aspects about the success of the surgical procedure, such as case-specific features of the target organs. Even though the need for novel kinds of feedback in surgical simulation has been presented [3], few studies have introduced methods for enhancing the feedback.

Observation of expert's demonstration is the basis for learning skills in surgery. Some simulators aiming for motion training provide expert's demonstrations within the simulation, for example Just Follow Me [4]. Research on haptic training (e.g. [5]) has been focusing on training of manual skills by using recorded expert's data, but demonstrations of such approaches in medicine are few. Virtual Haptic Back [6]

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introduced training of correct palpation paths along a virtual patient's back, but that approach is not essentially different from the trajectory training applications [5] in terms of real-time feedback.

Training strategies used in surgical training should be supported also in simulator-based training [2]. *Shaping* and *fading* are training strategies that some commercial simulators support [2]. *Shaping* means that the task is built little by little from its subtasks toward the full, complex task. *Fading* is an approach that reduces training aids when the learner's skill level rises.

Our approach for training of surgical skill is based on Annotated Simulation Records (ASRs) and visualization of behavioural parameters of interaction in surgery. In this paper, we summarize the essential concepts behind ASRs. Annotation is viewed as the means for modelling skill into recorded simulation. In order to use the ASRs for training, a novel technique for visualization of skill is presented: only the elements of "skill" are overlaid onto the simulation. An experiment was carried out to evaluate the proposed technique in abstract force exertion task, for which the example interaction was recorded by a cardiovascular surgeon on an aorta palpation simulator.

1. Annotated Simulation Records

The design of ASRs covers two essential aspects of surgical interaction. First, in order to determine what different behavioural parameters of surgical interaction constitute surgical skill, an annotation system has to be introduced. Based on the annotations, a model of surgical skill is constructed. Second, the model has to be presented to the user as a training aid, which is achieved through real-time visualization of the skill's components. The process of creating ASRs includes:

- Recording of example performances.
- Authoring of teaching scenarios: mistakes can be corrected and variable approaches created by editing the original recordings.
- Annotation of the examples: elements of skill are defined into the recordings.

Then, the ARS can be used as a training aid. Fig. 1 elaborates this process.

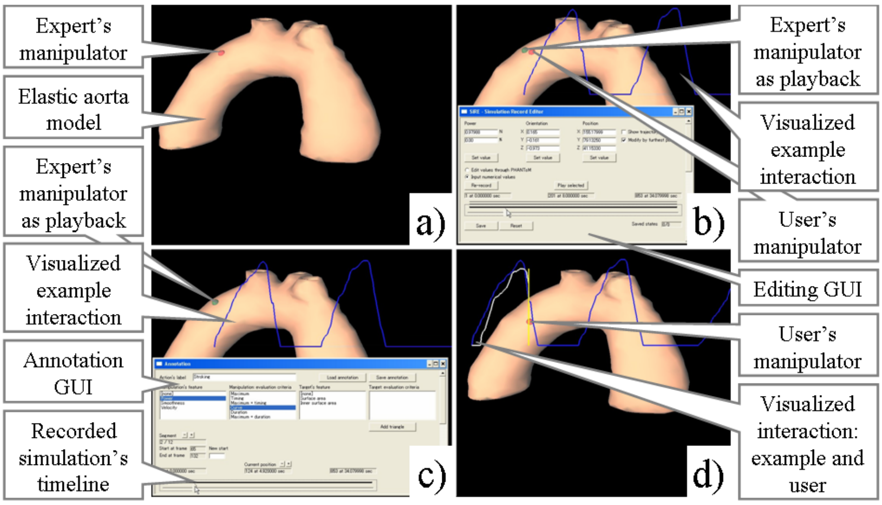

Fig. 1. The process of creating and using ASRs for palpation of the aorta: a) Recording of a simulation. b) Authoring: mistakes are fixed and variations created. c) Annotation: definition of what skill is composed of. d) Self-learning with the aid of SV which can be adjusted to match with the skill definition during training.

1.1. Annotation

Annotation is a common means to input meta-data about a subject. For example annotation of video sequences has made semantic searching of the content possible. Annotation can be thought as giving a meaning to parts or segments of the subject.

Within the ASR concept, annotation covers expert's insight about manipulation-level behavioural parameters of interaction in surgical procedures. The expert is given a means to determine what surgical skill consists of by defining meaningful segments of recorded example performance. Relations between relevant behavioural parameters of the performance are defined. Fig. 2 illustrates the nature of annotation.

1.2. Visualization

The visualization of the behavioural parameters is based on simplicity of 2-dimensional graphs overlaid on a simulator's screen. The example interaction is shown as a template that the user's interaction should match when visualized in real-time. The visualization serves two purposes. First, raw-data is visualized to give an impression of the nature of the interaction. This technique, Visualization of Behavioural Parameters (VBP), presents time-series data as curves. VBP is illustrated in Fig. 3a).

The second technique is a skill training aid: only the elements of skill are visualized. This technique can present the user's desired behaviour by displaying limits for the interaction, and therefore called Skill Visualization (SV). The possibility for this technique exists only in VR. In the real world it is not possible for a novice to perceive the skill as it is, since the skill itself cannot be presented, only the appearance of one of its instances at a time. Fig. 3b-d) elaborates the design of SV. SV serves four purposes:

1. Principle of interaction is directly perceivable.
2. Accurate and exact real-time feedback is achieved during training.
3. Fully proactive training, i.e. the haptic modality is not restricted in any way.
4. Applicable to also indirect effects of interaction, e.g. changes on the target.

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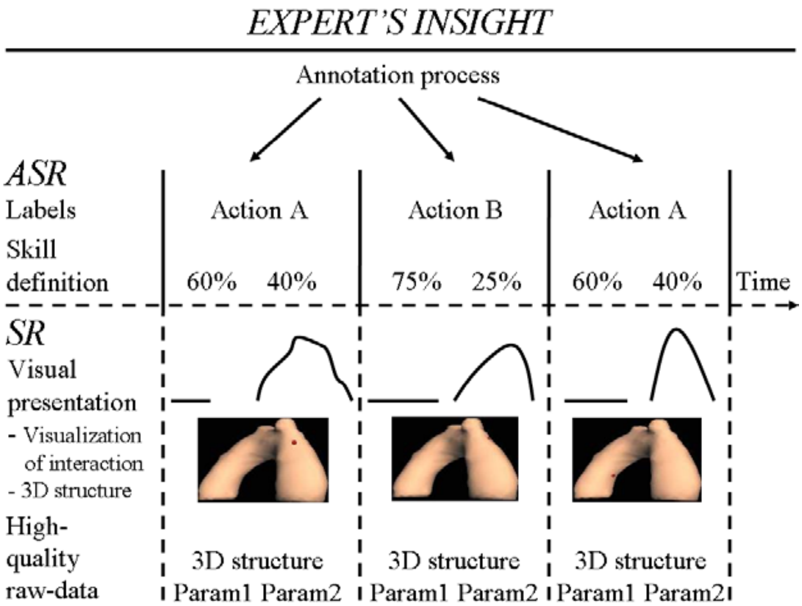

Fig. 2. ASR consists of a Simulation Record (SR) and annotations assigned to the segmented timeline of the recorded simulation: actions' labels and definitions of the elements of skill relevant to the action. Behavioural parameters of interaction (Param1 and Param2) are visualized to ease the annotation process.

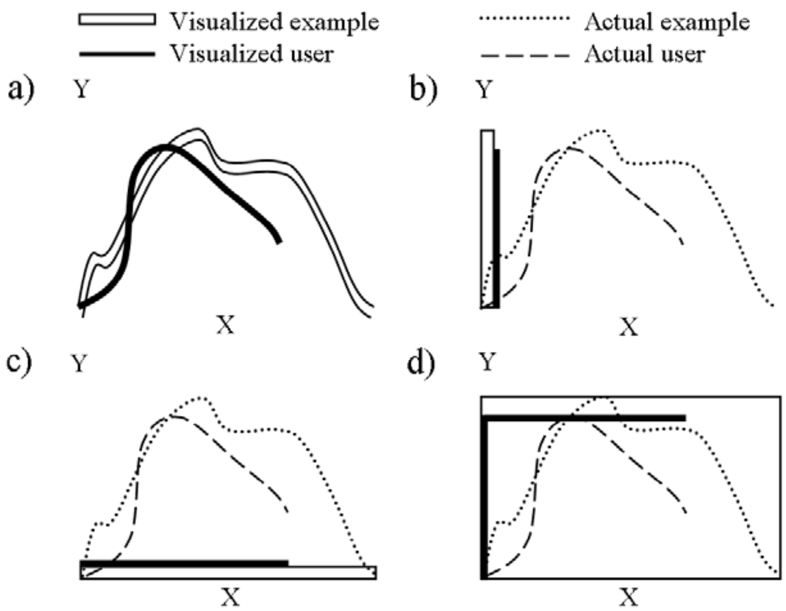

Fig. 3. a) VBP: Time-series data is presented as is. b-d) SV: The exact presentation of the example is hidden. Only the 2-dimensional axes indicate what the skill consists of. For example, the axes could be assigned as X=time, Y=maximum power. d) Two axes are combined to display only an approximate of the interaction, yet, showing the limits of the skill.

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Fig. 4 explains the role of VBP and SV in the process of creating and using ASRs for simulator-based training. VBP is beneficial for scenario authoring, segmentation of the timeline of the recorded simulation and definition of elements of skill through the annotation process. The intended use of SV covers mainly self-learning of surgical interaction on a simulator, but may be used also in the annotation process, too.

1.3. Training Using Skill Visualization

General skill models can be created by calculating averages or maximum values of ASRs recorded by different experts. The actions that are labelled as the same are grouped and averages are calculated for the annotated components of skill.

The SV technique can draw attention to chosen components of the skill at different phases of the training. When using the *shaping* training strategy, the training of a task can start from just one component, after which another one is introduced.

For the *fading* strategy, SV is capable of presenting all the components of the skill at one time. Then the visual aids are reduced one by one until the user masters the full task. However, human's capability to track several visual cues accurately is limited. Therefore, SV is expected to be beneficial mainly when using the *shaping* strategy.

1.4. Comparison to Earlier Training Systems

The traditional approach to learn motor skills is based on observation and mimicking of expert's performance, which has been incorporated into VR-based training. For example Just Follow Me [4] supports learning from expert's recorded example motions by displaying the examples as a "ghost" that the user follows in the virtual environment. This traditional approach does not draw attention to any components of skill.

Feygin et al. [5] reviewed haptic training systems. Most of them enhance learning by restricting or aiding the novice's motions. Haptic guidance has not yet met a grand theory and sophisticated systems are continuously under development. Haptic training systems have also been introduced to the medical field (e.g. [6]), but a general skill modelling system has not been realized. Since only visual cues are used, the VS technique does not have any restriction to the user's motions on the haptic modality.

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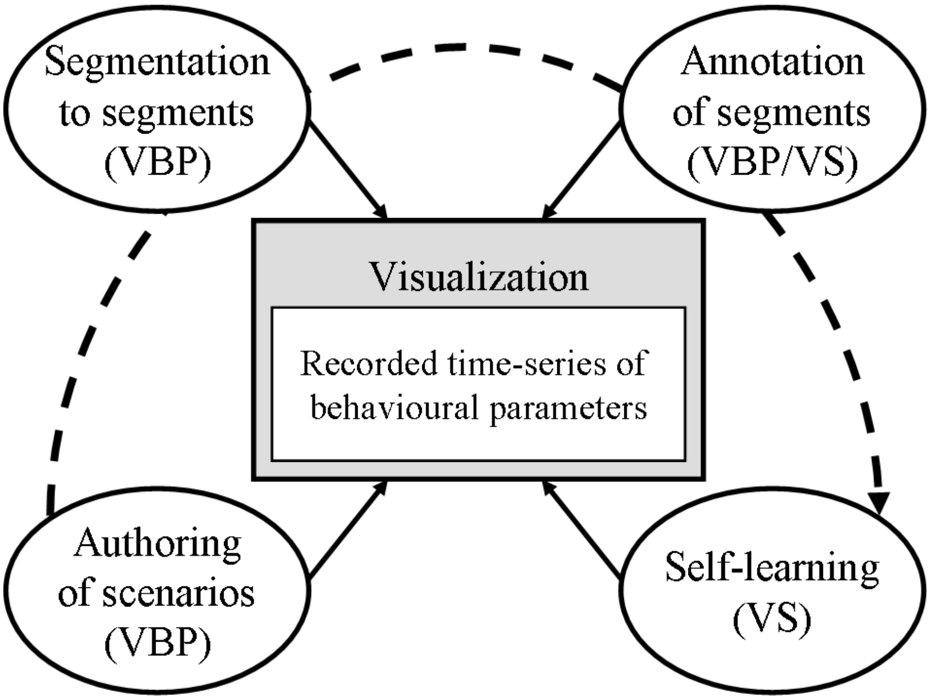

Fig. 4. The role of the visualization techniques in production of ASRs.

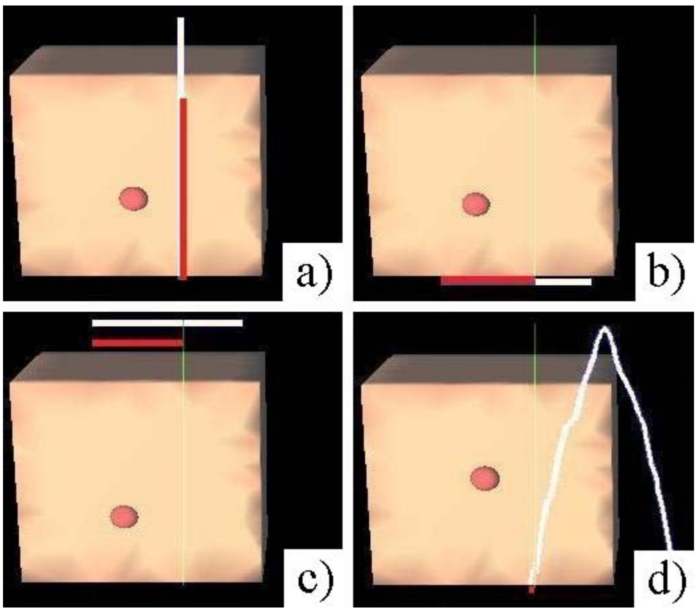

Fig. 5. Visualization conditions in the experiment. White: example. Dark: the user. The example moves from right to left and the user tries to match the lines. a) VS: maximum power b) VS: duration c) VS: maximum power+duration d) VBP: time-series.

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2. Experiment

Force exertion was chosen to be a concrete example to demonstrate skill visualization of fundamental interaction in surgery. The experiment was designed to display the difference between VBP and SV, thus to demonstrate the need for the two different visualization techniques. Subjects practised force exertion from expert's pre-recorded example performance. A cardiovascular surgeon from Kyoto University Hospital performed palpation of the aorta on the MVL simulator [7] on a Xeon 3.2 GHz dual CPU with 4 GB RAM desktop platform with a Sensable PHANToM™ device. His example performance was recorded at 100 Hz sampling rate. Two individual pushing excerpts of his interaction were selected from the recorded simulation:

- Example E1: Maximum power 1.25 N, duration 1130 ms.
- Example E2: Maximum power 1.18 N, duration 1930 ms.

In order to see possible differences caused by variable elasticity, two virtual elastic cube mesh models (782 triangles) were prepared with stiffness parameters 1.0 MPa and 0.1 MPa Young's modulus. Poisson's ratio was set to 0.4. The 1.0 MPa model had the same parameters as the aorta model that was used during the expert's recording phase.

Annotation of the recordings was done by the experimenter. In E1, the skill was defined to consist of maximum power as the most important component and duration as the second one. In E2 the order was duration, then maximum power. In this way, the subjects were to *shape* their interaction skill by starting from one component of skill and then adding another one to the task. At first, one of visualizations shown in Fig. 5a) and b) was shown, then another component was "added" as shown in Fig. 5c). For VBP the visualization was always as in Fig. 5d).

6 subjects were divided into Group A and Group B. Their task was to follow the examples E1 and E2 overlaid on the simulator's screen. The examples were evaluated by simply calculating the error between the example's and the user's maximum power as Newtons and duration as milliseconds. Group A practiced the tasks first with VBP and then VS. Group B started with VS. When using VBP the subjects were only told to focus on the specific components, but the curve was always shown. Each evaluated trial consisted of training with the visualized example and repeating from the memory. Each task (E1 and E2) consisted of 7 trial pairs (first: tracking the example, second: repetition from memory) in each training phase, resulting in 42 trials per task, 336 per subject and 2016 in total in the experiment.

3. Results and Discussion

The results are presented briefly in the following. Only the most interesting and statistically significant differences are discussed at this phase of the analysis.

Maximum power was in general easier to be tracked with VS than with VBP. Mean average error was 5.2% when using VS and 11.1% ($n=171$, $p<0.05$) with VBP when tracking the example. Every subject's best trial reached less than 1.4% error with both VBP and VS. The ease of following the example affected also the performance from memory: 12.1% with VS and 18.1% with VBP ($n=166$, $p<0.05$). The soft cube was the easier target for tracking the example's maximum power: 9.3% on the 0.1MPa model and 14.7% on the 1.0MPa model ($n=337$, $p<0.05$). This was suspected to be due to the different distance that the finger had to be pushed in order to exert equal amount of force on both cubes. Use of power was easier to be controlled on the soft cube.

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Most subjects reported counting seconds in their minds in order to remember the duration. For this reason, there were no significant findings related to mean average errors of duration. In the second training phase VS was proven better. When tracking the example, mean average errors of maximum power varied from 4.6% (VS) to 7.5% (VBP) ($n=340$, $p<0.05$). Performance from memory did not improve with VS, though.

4. Conclusions

A novel approach for simulator-based surgical training was proposed. By annotating experts' recorded performances on a simulator, the skill can be described. Presentation of the skill description to a novice is achieved by overlaying 2D graphs that visualize the chosen behavioural parameters of interaction on the simulator's screen. This paper introduced a technique for visualization of skill, which is only possible in VR. The example "skill" can be displayed component by component, which supports the *shaping* training strategy. The experiment evaluated the skill visualization technique in the case of force exertion and it was found useful for the *shaping* strategy.

Future studies will deal with multiple behavioural parameters of surgical interaction which could also be indirect effects of the surgeon's manipulation, i.e. dynamics in a surgical procedure could be explicitly visualized. Usability of the annotation tool for skill modelling is also a future research subject. Then, more complex skills can be modelled and the models used for assessment of skills.

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