Generating facial expressions of pain with projection mapping for the nurse training simulator (2nd report)

– Dynamic Projection Mapping Using Marker-based Tracking and Experimental Validation of Facial Expression Effect –

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1. Introduction

Patients with cerebral palsy suffer from permanent movement disorder, and nurses routinely aspirate their mucus where a tube is inserted into their trachea. The tube insertion procedure must be completed quickly and carefully while the nurse keeps watching the patient's facial expression to confirm that he/she does not experience inconvenience and even bleeding. The training opportunities should be frequently provided for novice nurses to master the treatment.

Several mannequins have been made for this training. Q-Chan® consists of the upper part of a body with an affordable price, and an endotracheal insertion is trainable [1]. However, it does not simulate any vital reaction of a patient such as facial expression. On the other hand, SimMan® consists of a full-body [2], and even patient's reaction like bleeding, and mouth and eyelid movement can be mimicked. However, it provides only limited vital reactions and does not simulate any facial expression. Furthermore, its high cost prevents the system being introduced into general education sites.

To solve the issue, we have developed an interactive endotracheal suctioning training simulator with projection mapping function that can provide a head mannequin with the pain sensor attached, can systematically generate the facial expression of the pain, and can project the computer-generated patient's facial expressions onto the mannequin face [3, 4]. The experimental results using our simulator showed that the facial expression change with sound decreased effectively the overall treatment time by 13 nurses and 9 students [4].

In the real treatment, the patients sometimes turn their body to the left or right side. However, the projection mapping in the current system [4] functions only when the mannequin is facing up. Therefore, we newly develop a function that enables a marker-based orientation tracking of the head mannequin and the dynamic projection mapping of the facial expressions along with the tracking result of the head rotation. The detail of the function will be explained in the report.

2. Overview of the Training Simulator

2.1 Simulator Configuration

Figure 1 illustrates the functions of our interactive endotracheal suctioning training simulator. It consists of a head mannequin equipped with load sensor, control PC, sensor controller, high-speed camera and projector. A speaker also produces the coughing sound. The pain sensor consists of 2 sensors; the end-point sensor that can sense whether the cap is put on/off, and load sensor to detect how deep the tube is inserted and to measure the contact force applied to the artificial trachea. The data from the sensors are sent to the sensor controller. The data from the sensor controller is then sent to the control PC to generate an image of a face with painful facial expression. The facial expression image is then projected onto the head mannequin by the projector. The coughing sound is also produced by the speaker once the tube is inserted through the artificial trachea. The camera captures the markers attached on the head mannequin for the orientation tracking, and its detail will be described in section 3.

2.2 Facial Expressions of Pain and Animation

To represent a quantitative model of a facial expression, we used Facial Action Coding System (FACS) [5] that can identify each of the unique facial action into action unit (AU) each of which has 5 intensity levels. Figure 2 describes the action units correspond to pain and its implementation. In the shoulder pain research [6], it was shown

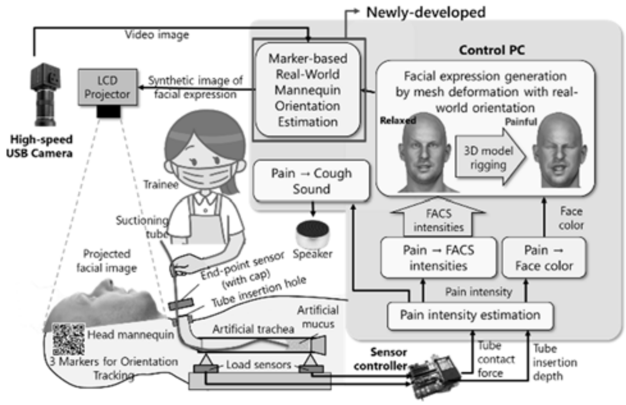

Figure 1. Overview of the Training Simulator

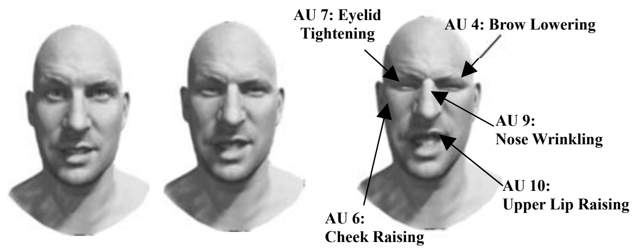

Figure 2. Three Painful Facial Expressions. Left: $p = 0$, Middle: $p = 8.5$ (Half), Right: $p = 16$ (Maximum)

that AU 4 (brow lowering), 6 (cheek raising), 7 (eyelid tightening), 9 (nose wrinkling), 10 (upper-lip raising), and 45 (blink) are considered as core pain related actions, and the estimation of the pain intensity from the observed action unit's intensity has been also studied [6, 7]. By taking the inverse of it, we originally propose a mapping from a pain intensity $p(\in [0, 16])$ to the intensity of an i-th action unit AU_i $(\in [0, 5])$ as Eq. (1) and (2). They are used to control the degree of pain in the facial expression of the head model[4].

$$AU_i = (p - 1)/3 \qquad (i \in \{4,6,7,9,10\}) \tag{1}$$

$$AU_{45} = \begin{cases} 0 & (AU_7 < 5) \\ 1 & (AU_7 = 5) \end{cases} \tag{2}$$

These action unit intensities are then used to deform each constituent on the 3D head model by the rigging operation with skeletal bone. The deformation results for painful expression are shown in Figure 2.

3. Dynamic Projection Mapping with Orientation Tracking

3.1 Marker-based Tracking

The projection mapping in our previous simulator only works when the mannequin is facing up as shown on Figure 3. However, in the real situation, patient might align their body to the left or right according to the body condition, and a nurse must take a suctioning treatment in these laterally facing posture. So, the system must realize the dynamic projection mapping that can generate an image appropriate to the head orientation of the mannequin.

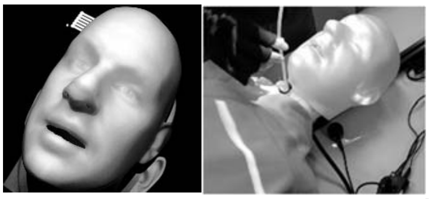

Figure 3. Previous Static Projection Mapping [3, 4]

Figure 4. Three Markers for Orientation Tracking

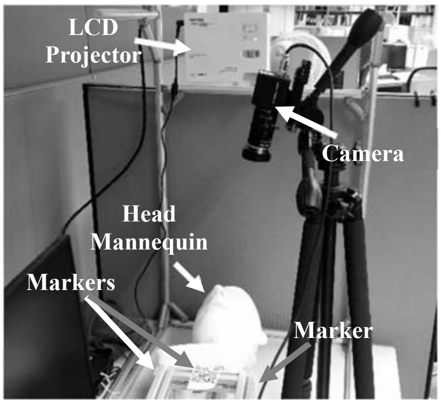

Figure 5. Dynamic Projection Mapping System Configuration

There is a common technology on Augmented Reality that superimposes virtual objects onto the reality using markers attached on a real object [8]. The marker is basically a chosen image, preferably the one that has good feature points to increase the detection accuracy and stability. The orientation of the marker in the real world can easily be tracked as it has unique feature points.

Three different markers are needed to accommodate the mannequin alignment to the left, right, or up. Vuforia library [9], available within the installation of Unity3D [9], already provides a robust marker tracking. The markers will be printed and attached to the mannequin and a camera will be used to detect orientation of each marker in the real world. It works by first assigning the feature point to the marker image then detects the feature point when the marker image shows on the camera.

3.2 System Setup

Because Vuforia library [9], available within Unity3D [9], already provides a robust marker tracking, we made use of this library to implement our dynamic projection mapping. We printed three markers shown in Figure 4, and different marker is attached on each orthogonal surface of a frame under the mannequin to enable the system to detect the mannequin alignment to the left, right, or up as shown in Figure 5 and 6.

The setup of our dynamic projection mapping is shown in Figure 5. Ideally, the camera should be put right on top facing like the projector, but in this case the whole mannequin with the marker does not fit the camera's field-of-view thus making it impossible to be tracked. For solving the issue, the camera was finally put right next to the mannequin to include only the marker image.

When using 20 fps standard web camera, it was observed that the image became blurry and tracking failed when the mannequin head was rotated. To solve it, a high-speed camera (Kayeton Co. Ltd, KYT-U400-MCS2812R01, 120fps at 1280x720) is used to avoid the marker image being blurry and to enable the more stable tracking.

3.3 Dynamic Projection Mapping Result

So far, the marker-based tracking works well. If the head mannequin is turned, the turned painful facial expression image projected on the mannequin can be seen. However, due to a dark surrounding, although the camera can still capture the image, the feature points were not tracked properly. This problem was solved by only illuminating the part where the marker was attached.

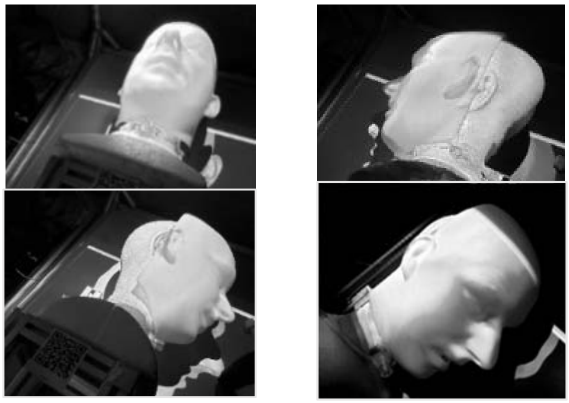

Figure 6. Marker-Based Dynamic Projection Mapping Results in the Different Orientations

The speed of the detection and tracking was also achieved at 120 fps, as the high-speed camera worked as expected and reduced the blur. A delayed response roughly around 1-2 seconds was observed until the next marker was detected during the mannequin rotation. However, it does not substantially obstruct the operation process of the simulator, as the nurse adjusts the patient's alignment once and starts a suctioning treatment without turning the patient's body again.

Before the dynamic projection mapping starts, several pre-adjustments must be completed to provide accurate projection mapping.; 1) aligning the projected image to the head mannequin, 2) moving the camera position, and 3) adjusting the distance of the LCD projector to the mannequin. These adjustments took roughly 1-2 minutes by the operator. Once the setup has been finished, if the mannequin stays on its position, no further adjustment is needed. The mannequin for now must be moved gently in order to keep aligning the projection mapped image to the mannequin. As shown in Figure 6, overall, the proposed idea of the dynamic projection mapping with orientation tracking in our training simulator works as expected.

4. Conclusion

The dynamic projection mapping with marker-based tracking proved to work for different orientations of the mannequin head in our interactive endotracheal suctioning training simulator. The small tracking delay was observed, but it does not obstacle the simulation procedures. As our future works, the adjustment procedures should be simplified. We will also investigate the effect of the facial expression in the training scenario.

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