Jointonation: Robotization of the Human Body by Vibrotactile Feedback

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1. Introduction

Movies, comics, and video games frequently involve robotic heroes composed of metallic parts. Although these characters exist only in the realm of fantasy, many of us would be interested in becoming them, if only for a short time. The question therefore naturally arises: how would it feel to be a robot?

We developed a virtual robotization system named Jointonation, which modulates haptic intonation of the human joint, as shown in Figure 1 [Kurihara et al., 2013a]. To create a realistic robot-like body sense, we provide the vibrotactile feedback constructed from the vibration recordings of real robot actuation, data-driven modeling based on spectral approximation, and vibrotactile rendering to the user’s elbow joint as a function of the elbow angular velocity (Figure 2). Combined with conventional visual augmented reality (AR) and sound effects, Jointonation virtually robotizes the user’s body visually, aurally and haptically (Figure 3). Our key accomplishment is the modulation of haptic intonation on the human body itself, which is an unexplored topic in haptics.

This work contributes to the field of computer entertainment technology by presenting a new alternative for achieving an immersive video game experience with gesture input interfaces. Some previous tactile entertainment systems have enhanced the video game experience by presenting tactile stimuli to the player’s body, synchronized with characters being shot [TN Games] or getting slashed [Ooshima et. al., 2008]. However, playable characters in video games are not always human – sometimes they are, for example, metallic robots. By creating a robot-like body sense and simulating a situation in which the player becomes the robot, experiencing the game with a robotic body could be made more immersive and intuitive. We envision that the technique of virtual robotization could enrich video games by offering an emerging experience of being a fictional robotic hero.

2. Related Work

A robot’s own internal motors and gears inevitably generate high-frequency vibrations that contaminate measurements of the robot’s movement and sound [Ince et al., 2009][McMahan et al., 2012]. We believe that these “ego-vibrations” are essential in the induction of a robot-like feeling. We propose to apply the annoying robot acceleration and noisy operating sounds to the human body and thus help to create a robotic body sense.

Vibration recording, modeling, and rendering are often used to alter haptic perception such as object stiffness [Okamura et al., 2001][Hachisu et al., 2012] or surface texture [Romano et al., 2012][Minamizawa et al., 2012][Kamuro et al., 2012]. These systems allow the user to touch a variety of objects in the environment. However, to the best of our knowledge, none of these prior studies has focused on altering the material properties of our own bodies.

We previously developed a system that virtually alters the feeling of a material on the body using periodic vibrotactile feedback [Kurihara et al., 2013b], which simulates the haptic properties of materials when they collide. In contrast, the present work focuses on creating a robot-like feeling. The ticking vibrotactile feedback we used in the prior system could simulate rubber, wood, and aluminum collisions, but these were not robotic feelings. To create robot-like “creaking” sensations, this work uses continuous vibrations captured from real robot actuation, instead of the discrete collision-based vibrations from the prior study.

An illusion of body-ownership called the rubber hand illusion [Lackner et al., 1988][Botvinick et al., 1990] is induced by simultaneously tapping on a person's hidden real hand and a visible rubber hand placed next to the real hand. The person feels as if the rubber hand has become their real hand. This illusion can also be provoked by the synchronous movement of the person’s real hand and a virtual hand on a screen [Slater et al., 2010]. In this study, we use this phenomenon to create the feeling of ownership of a virtual robot arm using synchronous movements of the user’s real arm and the virtual robot arm.

Figure 1. *Concept image of virtual robotization of the human arm.*

Figure 2. *Overview of the prototype system. The user (left) feels as if his arm became a robot arm on the monitor. The robot arm model tracks the user’s right forearm.*

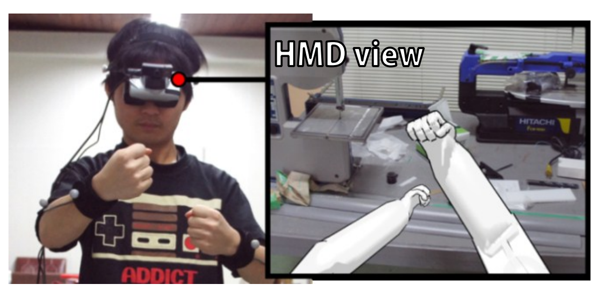

Figure 3. *Appearance of AR Jointonation and the HMD view.*

3. Principle and Verification

Our hypothesis is that presenting robot ego-vibrations to the user's joints in accordance with their motion will make the user believe his or her body has become robotic. Thus, we employed a data-driven approach using vibration recording, modeling, and rendering (Figure 4), which has been reported to be a promising method in the creation of realistic virtual textures [Romano et al., 2012].

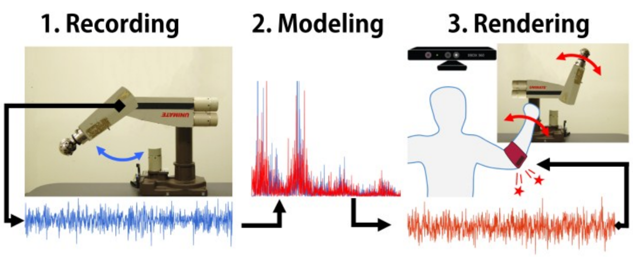

Figure 4. *Data-driven approach for robotization of human body.*

Haptic recording. We recorded the high-frequency vibrations of the elbow joint of a robot arm (Unimate PUMA 260) that generates a strong vibration that humans can clearly recognize. The elbow joint was actuated at 0, 10, 20, 30 … 80 degrees per second in each direction. Note that actuation at 0 °/s means that the robot was actually stationary, but it still had some background vibration from its other components. During each operation, a three-axis accelerometer attached to the elbow joint recorded the acceleration data at a sampling rate of 2.5 kHz to capture what the robot felt as it moved at the specified angular velocity. A microphone was also attached to the joint to record sound.

Acceleration data modeling. We performed simple processing steps to create a vibration model from each raw data recording. First, we applied a 20 Hz high-pass filter to remove low-frequency components attributed to the change of orientation of the robot's forearm. Next, the three acceleration channels were summed to a single wave. We then calculated the coefficients of linear predictive coding (LPC) as a function of angular velocity, to make a model that approximates the spectral density of the raw data as shown in Figure 5. The LPC coefficients, a series of past data samples, and a sample of white Gaussian noise can be combined to calculate the next vibration signal. While the model contains a similar spectral density to the raw data, the model in the time domain is not a representation of the same waves because of the randomness of the white Gaussian noise. Therefore, users can feel natural continuous vibration.

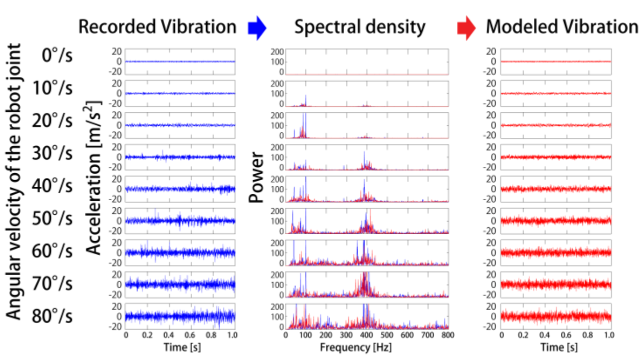

Figure 5. *Recorded vibration (left), example of LPC-modeled vibration (right), and overlaid spectral density (center).*

Rendering a haptic intonation. Figure 6 illustrates the system structure of our prototype system. When the user moves his or her elbow joints, a microcontroller computes the appropriate vibration signal and actuates the vibrotactile transducer (Alps Electric, Force Reactor) attached to the user's elbow with an armband. The vibration signal is matched to the angular velocity of the elbow, which is captured by a Kinect camera. The visual model of the robot is displayed and animated in front of the user, and the operating noise of the robot is emitted from a speaker attached at the user's elbow.

Latency evaluation. We measured the latency between the user's real arm movement and the virtual robot arm movement at the elbow joint. When the real arm movement was about 90 °/s angular speed, the latency was approximately 50 ms. Most of the latency was due to the camera. Because the gap was less than the latency (100-200ms) allowable between human motion and graphical responses [Dabrowski et al., 2001], we considered it to be sufficiently small. In a preliminary demonstration to our laboratory members shown in Figure 2, none of the participants noticed the latency. The reactions of the participants appeared to be positive such as "My arm became the robot's arm" or "I have motors and gears in my elbow".

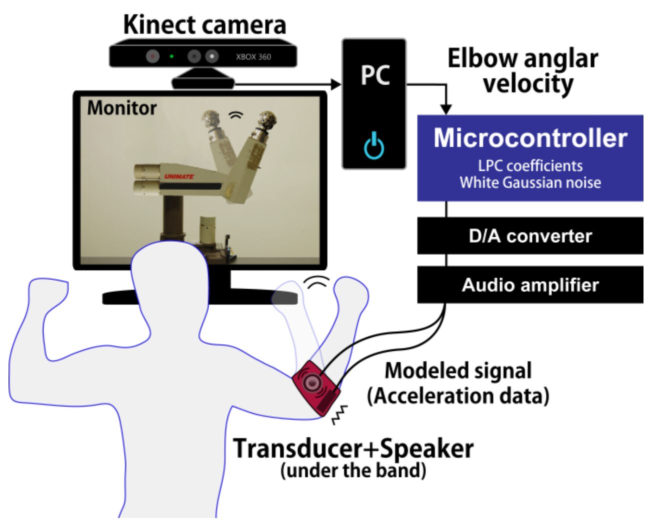

Figure 6. *Hardware setup of the prototype system. In AR Jointonation system, we will use an HMD instead of the monitor to superimpose virtual robot arms on the user's arms.*

Verification. We carried out a psychophysical experiment with the prototype system to verify the contribution of vibrotactile feedback to the subjective robot-like feeling [Kurihara et al., 2013a]. We compared four conditions; 1) visual only, 2) visual + auditory, 3) visual + haptic, and 4) visual + auditory + haptic, by means of questionnaires, asking users to evaluate the amount of robot-like feeling with a visual analog scale. We also asked subjects to state the amount of pseudo reaction force they felt, which was often mentioned in a preliminary test and may be a good quantitative measure of subjective unification of their arm with the robot arm.

The results showed that the robot-like feeling of visual + auditory + haptic condition was significantly higher than all the other conditions. The pseudo reaction force was perceived significantly stronger whenever vibrotactile feedback was applied. This result suggests that the combination of the visual, auditory, and data-driven haptic feedback was the most effective in enhancing the robot-like feeling.

3. AR Jointonation at Demonstration

We will demonstrate an AR system that virtually robotizes the visitor's arms with a video see-through head mounted display (HMD) and two armbands that each contain a vibrotactile transducer and a speaker. A camera mounted on the HMD captures the visitor's view and tracks markers attached on the arms; the HMD shows robot arms on the participant's arms, as in Figure 3. By robotizing the visitor's arms visually, aurally, and haptically, the AR Jointonation system will give users a new experience of becoming a robot.

We can alter the user's body to feel like various other objects with a similar setup. We have tested a clicking multimeter dial, a water-spurting garden hose, a groaning vacuum cleaner, and peeling Velcro tape. We observed that vibrotactile presentation of these materials provides a weird body sense, like ticking-dial elbow, water-spurting or air-breathing palm, and Velcro arm.

Acknowledgements

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