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Biometric Visceral Interface: A Soft Robotic Immersive System for Extended Perception

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Abstract
The concept of a Biometric Visceral Interface originates from a search for an alternative to the visual presentation of biometric data. Departing from the habit brought by the spectacular society of seeing and understanding, Biometric Visceral Interfaces challenge the common practices of communication based upon visual memory and quantified abstraction of biological phenomena. The aim of such interfaces is to extend human perception of body information beyond visual paradigm and semiotic objects. A set of biomorphic designs of soft robotic prosthetics is introduced here to define a new human-machine interface that allows the users to have affective interpersonal communication. We describe how a multisensory immersive system can reconstruct a user's body schema in virtual space and visceralize biometric data into the user's body as a new way to perceive the presence of others.

Keywords
Data Visceralization, Soft Robotics, Haptics, Virtual Reality, Affective Computing, Biometrics.

Introduction

Existing biometric technology has enabled people to observe and understand the biological events and state changes in their bodies. It provides a reliable and objective way by which various body phenomena can be converted into quantified information that is shareable among people. Biometric information in the form of data can be segmented, analyzed, interpolated, machine learned, and fused in certain ways so that a meaningful and accurate description of a person's biological traits and conditions can be made interpretable [1]. We are particularly interested in mapping, mediating and transforming a user's biometric data to allow another user to gain some understanding of the body through cutaneous senses. We focus on how soft robotics and virtual social space can facilitate such experience, and how affect can be conveyed through these new methods.

Haptics plays a critical role in creating affective communication among the users. Certain amount of touch everyday can enhance affect and convey stronger sense of bond between people [2]. To perform affect transfer between individuals and elevate a user's perception of touch from mere feeling into recognition of others, several design factors need to be explored. Among all of them, the major questions are where the device is actuating on the body, how strong and how much sensation a user is experiencing, and what spatiotemporal pattern of touch sensation is actuated. We predict that these factors can influence how much affect and even how much information a user can decode from the actuation of a piece of biometric data.

Figure 1. (a) A user wearing a Biometric Visceral Interface and navigating in a computer-mediated virtual space. (b) A soft robot actuator on a user's neck. (c) A haptic link between the user and the device that incorporates pulse sensing on the user's ear.

Computer-mediated virtual space, on the other hand, serves as an environmental factor and can alter how a user is perceiving her own body. Recent technologies for Virtual Reality (VR), specifically Head Mounted Displays, (HMD), produce not only high levels of immersion, but also a strong sense of presence and embodiment [3]. An alternative body avatar in virtual space that is different from a user's actual body can potentially cause significant behavioral changes in the user [4]. The plasticity of the brain can cause a person to change and adapt her body schema to a virtual avatar that is not consistent with her normal body proportions, when she is given a certain amount of multisensory and sensorimotor body information [5][6]. This gives us inspiration that visceral perception of events external to a user's body can possibly be achieved when these events are "incorporated" into a new body schema that is reconstructed in our brain by multisensory stimulation [7].

Based upon these factors, we have built an immersive system that utilizes a soft robotic agent and an HMD with virtual avatars to facilitate multisensory visceral communication in a computer-mediated space. We name this new system as *Biometric Visceral Interface* (BVI) (Figure 1). In the following description of the BVI system, we discuss background, system, initial results and future directions of how soft robotics and VR technology can be used together to improve interpersonal communication and data visceralization.

Background

The practice of data visceralization draws upon previous concepts explored in the domains of tangible media and affective communication and is concerned with conveying information through sensations of touch [9], scent [10], vibration and warmth [11]. In this work, we are interested in how touch and vibration, those sense datum fundamental to our understanding of material properties (e.g., texture, mass, curvature, etc.), can work in conjunction with visual and auditory senses in order to give users a sensation of another presence inside her body as a way of visceral mediation.

In prior work, we discussed the development of a soft robotic prosthetic device, the *Biometric Perception Interface* (BPI), a wearable hardware interface that serves to extend perception for the purpose of affective computing [8]. The BPI system is divided into three parts: *Memorizer* (data center and controller), *Choker* (wearable actuator), and *Antenna* (linker and sensor). The system extends concepts that have been previously explored in soft robotic design, intimate communication, and remote haptic interaction [12][13]. We used soft materials to fabricate a pneumatic wearable actuator that can fit comfortably on a human body. It can physically link two people's bodies to give them haptic experiences of each other's pulses in real time without being in physical contact with one another. The BVI system we describe in this paper uses part of the BPI as its haptic infrastructure, and we implemented new designs that work along with VR technologies for multisensory immersion.

System

Our BVI system builds upon the design requirements for interpersonal haptic communication featured in the BPI, such as real-time biometric signal sensing, pulse simulation, on-body soft actuation, and push-pull connectivity for fast and portable linking between users. In order to integrate immersive visual experience to alter a user's self-body awareness, we identified new design requirements: extended range of movement that the user can walk with the device in physical space, quick placement on body and release, hands-free biometric signal sensing and haptic actuation, and networkability and software integration for social VR applications. These design constraints required us to formulate a new system by taking VR system as a critical factor into the design process. In a virtual environment, synchronization between the visual and the haptic elements must be prioritized in order to provide a coherent visuo-haptic experience. The physical mechanism of the BVI system need to communicate with the VR system at a latency as low as possible. Given the above constraints, we designed our BVI components with a focus on wearability, connectivity and visual synchronization (Figure 2).

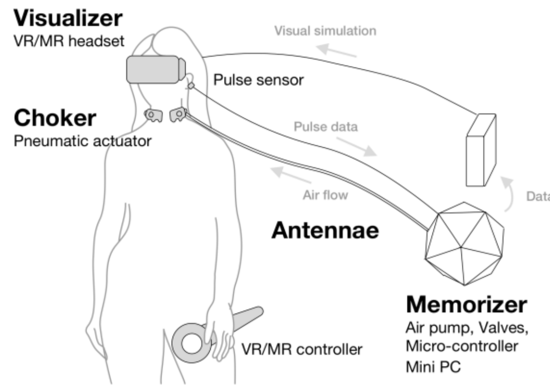

Figure 2. Installation diagram of a Biometric Visceral Interface.

Memorizer

The *Memorizer*, in this design iteration, serves as the data computation center and control mechanism. It handles jobs such as signal processing, pulse simulation, data communication, and virtual body rendering. The electronic peripherals embedded in a memorizer contains a mini air pump, a pair of valves, and an Arduino microcontroller. The visual computation is handled by a high-performance mini PC that has the processing power for VR graphics.

The haptic mechanism and visual data representation are separately handled on two different processing units, because we see the gap on computational workloads between the hardware and the software. The hardware control for the haptic interface requires very minimum amount computational power for signal processing and pulse simulation, as the pulse wave from a person can be easily converted to on/off signals for the valve system. We programmed a threshold-based switch that detects wave peaks to control the inflation pattern of the soft actuator. The ATmega328P microprocessor on the Arduino board is well capable of the amount of computational work on this part.

While the microcontroller is controlling the haptic component, the sensor signal is transmitted to the mini PC unit via serial communication after acquiring the data. The serial rate is set to be 115200 bits/second which ensures a fast data transmission in between the two units.

Choker

The *Choker* is a wearable soft haptic actuator that is to be worn on a user's neck. We use silicon based high performance rubbers to cast a soft and stretchable skin-safe pneumatic structure of varying degrees of elasticity (Figure 3).

When compressed air is pumped from the memorizer, an array of air channels on the choker's surface will inflate or deflate to morphologically simulate pulsing movements. In order to make it simple for wearing, we place a bendable metal wire inside the choker so that it can quickly fit onto a user's neck and stay there by itself with a proper neck shape. Push-pull connection ports for air tubing are designed on the back for fast release from the whole system.

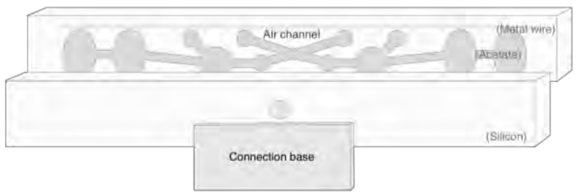

Figure 3. Structural design of the choker with air channels

Antenna

The *Antenna* is a cable-like multi-section connecting agent that links the memorizer, the choker, the visualizer and the users. An antenna provides air flow transmission and data communication via air tubing and electrical wires. It is designed to fit with the push-pull connection ports of other components for quick setup. A pulse sensor with a clip is placed on one section of the antenna to sense a user's heart rate on her ear.

Visualizer

In order to integrate the VR system into our visceralization research, we added a new *Visualizer* component to the system (Figure 4). The visualizer, connected to the memorizer and placed on the user's head, serves as an entry point to immerse into the computer-mediated space. It renders and maps a virtual body onto the user to give her a perception of an alternative body presence. A visualizer supports the most recent VR technologies on the market such as HTC Vive and Oculus Rift that precise tracking is integrated to give the user strong and responsive sense of immersion.

We use Unity game engine to generate real-time interactive 3D graphics in the visualizer, as Unity is well optimized for high-quality stereoscopic rendering and for GPU-based parallel computing. We designed voxel-based generative body avatar to induce the user to have an ownership illusion and to reconstruct the user's body schema. The pulse data is mapped onto the voxel particle flow that vibrates the virtual body to create an animated, dynamic and volatile sensation of visceral penetration beyond the body membrane (Figure 5). User orientation and positional tracking of the head and hands provides a visuo-motor congruence between the real and virtual when the user is walking, rotating the body and waving the hands. Placed inside an abstract and decontextualized space, the voxel-based virtual body is designed to enhance the user's level of immersion, so that the user can have a stronger sense of body ownership that takes her perception beyond the physical limits.

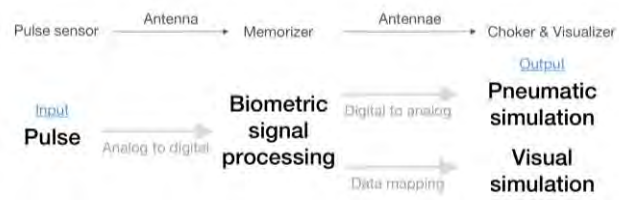

Figure 4. System diagram of a Biometric Visceral Interface

Interaction

Two different operation modes are designed in our system: local mode and network mode. In local mode, user can experience either pulse data stored in the memorizer or a real-time signal directly from the pulse sensor on the antenna as the source of visual simulation and physical actuation. A single BVI system can be used by two users sharing one memorizer, although the system can deliver visual simulation to only one visualizer. In such a case, a visualizer and two sets of chokers and antennae, are connected to a memorizer. The two users, being physically in the same space, can sense each other via soft robotic actuation on their necks. An extra projection screen can be connected to the memorizer to share the content from the HMD.

In network mode, a single BVI system is used by each user and each device serves as a node in the network. A connected user can wear a BVI system and remotely sense another user's biometric signal in real time. The memorizers telecommunicate with each other in the form of a remote visuo-haptic link. The computer-mediated space, in other words, becomes a social VR space where interactions are happening over the network. The users can encounter each other without being present in the same location.

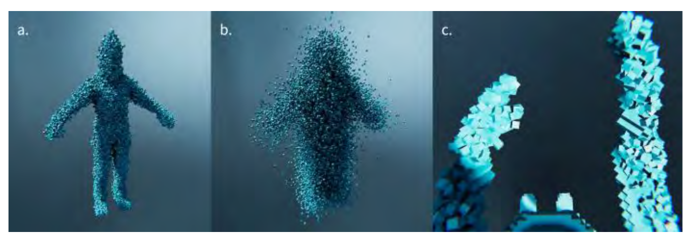

Figure 5. A voxel-based generative virtual body avatar can have different states: (a) deflated stable shape when pulse signal is low, (b) inflated and volatile expansion when there is a heartbeat. (c) dynamic movement with the user's tracked hand poses.

Network Protocol

In order to reduce the bandwidth usage, we only send pulse data between the nodes over the internet. We use ZeroMQ [14] messaging interface with TCP protocol to achieve low-latency and reliable data sharing. Specifically, we use asynchronous publisher/subscriber mode in ZeroMQ that starting the messaging nodes in the network are independent of each other and they can broadcast messages to others without making requests and responses. This allows the data to be transmitted with much lower latency.

Initial Results

Our design of a multisensory immersive system for extended perception using both soft robotic haptics and VR technology not only gives the user a visceral sensation of another presence in the body, but also provides a new way of affective interaction in a social cyberspace. The placement of our device onto a user's body, including an HMD, takes less than 15 seconds. The choker we designed for the BVI system is highly bendable but can still stay tightly on the user's neck. The user, while wearing the whole system, is also given complete freedom of turning, walking or using VR controllers with both hands. Inside the HMD, the user can see a tracked voxel-based virtual body on herself. The generative pulse animation on the virtual body is synchronized with the soft robotic pulse actuation on the user's neck. The network mode of our system also allows the same experiential link to be made over the internet.

Conclusions and Future Work

Our BVI system is capable of visceralizing biometric data to the user's body by visuo-haptic reconstruction of the body schema. Our system has many other potential application scenarios, such as multisensory immersive movie theaters, augmented telecommunication, and touch-based therapeutic art installations.

Future work will explore the idea of affective computing using the latest mixed reality technologies, such as the Magic Leap One and HoloLens 2 to further mediate and mix the user's sensation of the physical and the virtual, so that the visceralization of another person's biometric data can be more naturally achieved. We will also conduct user studies to evaluate the performance of our system based on the level of visceral and affective sensation, and overall user-friendliness of the hardware and software interface.

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