The cutting edge of haptic gloves

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Abstract*—With the commercial use of virtual reality headsets becoming widespread as of today, the attention of ambitious companies shifts towards the incorporation of a realistic sense of touch, in addition to audiovisuals, as the next step to expand the boundaries of immersion inside the virtual world. HaptX and Dexta Robotics, two companies in the forefront of glove-focused haptic technology, have different approaches to the implementation of this sense of realism and its delivery to firstly enterprises, but ultimately to ordinary customers as well. Although the current state of their products, the HaptX glove and the Dexmo glove respectively, is both already remarkable, and further promising, there seem to be some obstacles present which might be difficult, and in some cases, downright impossible to overcome. In this paper, the fundamental theory and reasoning behind the mechanism and design of these gloves will be discussed, their precursors mentioned, as well as the foreseeable future challenges they are bound to face pointed out.

Keywords*—degrees of freedom, exoskeleton, force feedback, haptics, motion tracking, tactor, tactile feedback, vibrotactile feedback, virtual reality

I. Introduction

Since the humble days of computers having keyboards as their only means of user input, there has been a great deal of effort put on bringing them closer to the user, customizing input devices to fit human needs, in order to ensure convenient and efficient cooperation between human and machine. Some milestones include the implementation of graphical user interfaces, the invention of the computer mouse, and the start of a transition to 3D with virtual reality in certain areas lately, as well as using voice recognition technology and many other contemporary approaches. While the advancement in user interface technologies is a matter of convenience for most of us, there are less fortunate people who are in desperate need of these innovations just to perform tasks we consider ordinary and mundane, so whatever one's reason might be to take interest in the development of these innovations, the end result is both enjoyable and noble. This report will focus on, in some sense, an extension to the aforementioned VR, but instead of audio or visuals, the emphasis is going to be on the feeling of touch, as another one of our five basic human senses. The area dealing with the sense of touch is called haptics.

Although motion capture technology has been around for quite some time now, and motion tracking is already included in today's VR sets, it is one way only. The user is a disembodied ghost, and while interaction with objects in the virtual space is possible, it gives the user no feedback in terms of haptics, other than small vibrations in the controller. This greatly breaks the immersion. Haptic gloves are meant to remedy this shortcoming of the current VR experience, by providing certain types of feedback to the user.

II. Theory

A. Motion tracking

In order to solicit haptic feedback from the virtual world, first we have to let the computer know the position and rotation of our real-world hand, which will be mimicked by a corresponding virtual hand inside the software. There are multiple ways of doing motion tracking, some more reliable than others. These include optical systems, using inertial measurement units, magnetic systems or the combination of these. It is important for the motion tracking to be precise and quick enough, otherwise, the resulting experience is not going to be believable for the user [4].

B. Force feedback

Force feedback, also called kinesthetic feedback, is the part of haptic feedback which simulates the inertia, shape, weight and deformation of an object [1]. It affects the receptors in a person's muscles and ligaments. Force feedback is typically implemented by an exoskeleton attached to the dorsal side of one's hand. We differentiate between two kinds of force feedback [3].

1) Active force feedback: An active force feedback system usually operates with motors. These motors can apply force to your fingers. This raises safety concerns, since in the event of some kind of an unexpected error, it can possibly result in injuries. Another drawback is that using motors increases the size and weight of the device by a considerable amount, as well as makes the structural implementation more complex.

2) Passive force feedback: This is the other type of force feedback. This one is incapable of applying force to your fingers and merely acts as a brake, resisting the force that you apply. This is completely safe, however, it lacks some realism compared to the active system.

C. Tactile feedback

Tactile feedback is the other component of haptic feedback, focusing on sensations such as temperature, vibrations and texture [7]. We feel these with our skin, where the vast majority of our receptors can be found [3]. When talking about haptic devices, they typically substitute this with vibrating motors, creating a symbolic tactile feedback, referred to as vibrotactile feedback. These vibrating motors are similar to the ones used in phones or game controllers [5].

In order to better understand the difference between these two types of feedback, one can experience only tactile feedback by touching an object placed on a slippery surface, from one direction only. You can feel the texture of the object with your skin, but there is little resistance. Similarly, you can experience only force feedback by wearing very thick gloves, basically filtering out the sensations you would feel through your skin [1].

The successful combination of these two types of feedback contribute to a realistic sense of touch.

III. HISTORY

When discussing the history of haptic gloves, there are two examples particularly worthy of mentioning.

A. CyberGrasp

For a long time, the CyberGrasp glove, developed by Immersion Corp (now CyberGlove Systems) had been the sole commercial force feedback haptic glove. It has been described by some as being ahead of its time, and being a forerunner to all commercial exoskeletons [1]. It uses a separate glove under the exoskeleton, called CyberGlove, to track hand movement. Other products sold by CyberGlove Systems include CyberTouch, which provides vibrotactile feedback, and CyberForce, which is an armature providing three degrees of freedom of force feedback to resist movement of the hand in space [8,9].

(a)

(b)

Figure 1. (a) The CyberGrasp glove, the first commercial exoskeleton; (b) The CyberForce armature [9]

B. Rutgers Master II

The Master II glove, developed by Rutgers University, was an attempt to make a lightweight and compact force feedback device. It was never a commercial product. Contrary to most force feedback devices, the Master II chose to restrict finger movement not from the dorsal side with an exoskeleton, but by pneumatic tubes placed inside the palm, applying force to the fingertips. It performed better in multiple aspects, than the CyberGrasp glove, but its one big disadvantage was that due to it being designed to be on the palm side, it prevented the complete closing of the hand in the event of grasping something. Contemporary devices follow the exoskeleton solution, making this glove somewhat of an odd one out [13].

Figure 2. The Rutgers Master II-ND [3]

IV. HAPTX GLOVE

The HaptX glove is the most ambitious and most sophisticated haptic glove so far. It uses HaptX's own patented microfluidic technology, and comes with a Software Development Kit with plugins for Unity, Unreal Engine 4, and a low-level C++ API [10]. HaptX does not hide the fact that they are the high-end of this technology, and thus they create their products with enterprises in mind, with a bigger form factor and a higher price point than what is suitable for the consumer market [2].

A. Implementation of motion tracking

HaptX promises unparalleled accuracy with sub-millimetre precision when it comes to motion tracking, as well as occlusion-free interaction [10]. It uses an electromagnetic solution, with a little emitter in the glove which creates a small magnetic field around it, and tiny sensors in each finger [3]. HaptX's software also automatically creates an individual, anatomically accurate hand model upon putting the glove on, which makes manual calibration unnecessary [10].

B. Implementation of tactile feedback

Tactile feedback is where the HaptX gloves stand out the most. While other gloves use vibrotactile feedback, HaptX uses a so-called "haptic skin", a microfluidic, silicone-based smart textile containing an array of pneumatic actuators and microfluidic air channels. There are 130 of these pneumatic actuators in each glove, and they are pushing against the user's skin, with variable pressure, up to 2 millimetres, displacing it the same way a real-life object would, and doing all of this with no perceivable latency [10]. These pneumatic actuators are referred to as "tactors" grouped in panels, and the 130 of them are not evenly distributed across the hand, but according to the surface density of the hand's nerve endings [4].

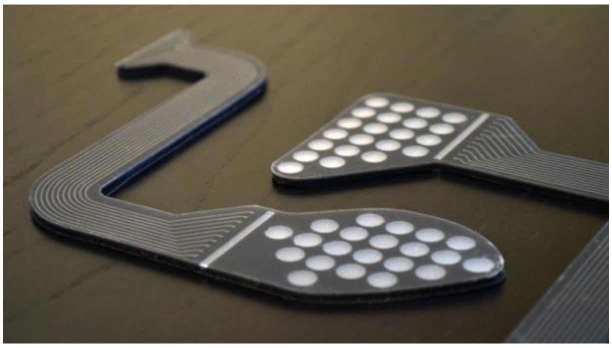

Figure 3. Two panels of inflatable tactors [10]

C. Implementation of force feedback

The HaptX glove uses passive force feedback [3]. The exoskeleton is described as ultra-lightweight and is powered by the same microfluidic actuation technology as the skin. It applies up to 4 pounds of force (~17.79 N) to each finger, and operates almost silently [10].

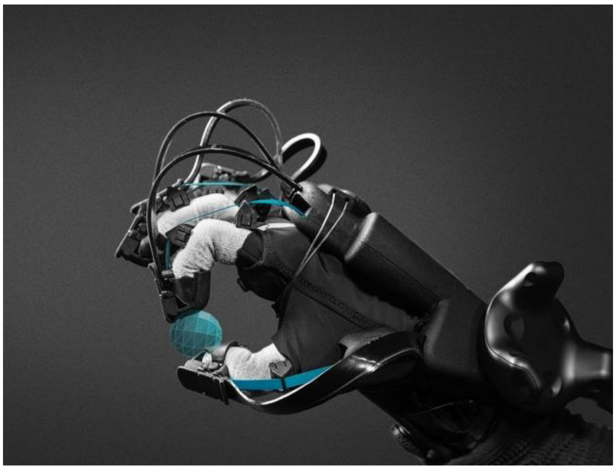

Figure 4. The HaptX glove grasping a virtual sphere [10]

V. Dexmo glove

The Dexmo glove is the opposite of the Haptx glove when it comes to where the emphasis is put. It is not as nuanced in its capability but it provides the essential things, all packed in a stylish and lightweight exoskeleton with a form factor as small as possible, and although the current targets are enterprises, Dexta Robotics shows willingness to make it available to the consumer market in the not so distant future [14]. Xiaochi Gu, founder and CEO of Dexta Robotics said they are capable of manufacturing and shipping this device [6]. The Dexmo glove supports Unity and Unreal and it is wireless, with rechargeable batteries.

A. Implementation of motion tracking

Rotational sensors are being used for tracking, providing 11 degrees of freedom, 3 for the thumb and 2 for all the other fingers. Every user's hand needs to be calibrated with different hand gestures upon the first use, but these can be saved into a profile for further use.

B. Implementation of tactile feedback

Concerning tactile feedback, a standard vibrotactile feedback is used at each of the fingertips, as well as at the palm inside the strap, and on the dorsal side of the hand.

C. Implementation of force feedback

The Dexmo glove uses active force feedback, executed by servo motors providing feedback only in one degree of freedom for each finger. Initial prototypes had feedback with more degrees of freedom per finger but this would have affected the weight of the device so much that they decided to limit it [6].

Figure 5. The Dexmo glove [11]

VI. Applications

A. Design for manufacturing, for automotive and aerospace

Ever since CyberGrasp, one particular area of application for haptic gloves has been the automotive industry [8]. The feeling of touching a virtual 3D model is a much cheaper alternative to designing real-world prototypes.

The Nissan Leaf, the world's best-selling highway-capable electric car, and the Nissan IMs, the fully electrified luxury sports sedan concept car are some of the vehicles in which HaptX gloves were involved in the design process [12].

Figure 6. A screen capture from Nissan's VR vehicle design involving Haptx gloves [12]

B. Simulations

Another area of application is for training simulations across defence, industrial and medical applications. Haptic feedback helps build muscle memories needed for the real-life task, the simulation is infinitely repeatable, and certain hazards, posed by live training, are avoidable [10].

The Haptx team has worked together with the San Luis Obispo fire department, building a pump panel training simulation. This has saved the fire department an immense amount of water which would have gone to waste in a live training scenario [10].

Figure 7. Haptx's pump operation tutorial [10]

In partnership with Engineering & Computer Simulations, HaptX has developed a medical training simulation called Tactical Combat Casualty Care, which provides step-by-step directions for combat medics, to treat injuries sustained in battle [10].

C. Entertainment

This area of application is the one which concerns mass consumers the most, and also the one which is likely to be the last one to be realised due to the current price point of these devices. HaptX's plans are more on the location-based entertainment side, like theme parks and arcades [5], while Dexta Robotics seems to have portable devices in mind, which can be owned by individual people [14].

VII. Future and challenges

These devices, although already having working prototypes, are still in development, and they are certainly going to have even more features eventually. HaptX was seen having some kind of a temperature-related system under development behind the scenes [4], but it is not part of the glove yet. The box for the valves controlling the airflow to the tactors in the HaptX glove is relatively big as of now, but Jake Rubin, the founder and CEO of Haptx insists that in time, they are going to be able to miniaturise the system with their custom, optimised valves to such an extent that the whole system is going to be able to be made into a wireless device [2]. One particular challenge for these products, is finding a way to be brought to the consumer market with a reasonable price, but it was the same thing with VR sets and they have eventually found a way, so it is just a matter of time. Everyone who tries these gloves seems really impressed by them, so the demand is there.

Another challenge is all the compromises having to be made during the design. It seems like if you cater to one need, you always have to sacrifice another. The device must be lightweight, to prevent user fatigue, but the more complex and competent it is, the heavier it gets [6]. Realism is bound to be sacrificed for safety, because realistic touch can be painful and even resulting in damage, but selling a potentially dangerous device to this capacity would never be a viable option [3]. Lastly, this research has not been able to find any recent haptic device restricting the degrees of freedom of the hand in space. The CyberForce armature has already proven the viability of such a system [8], but presumably the reason why nobody has been following in its footsteps, is because it would go against the portable and compact nature of these devices. Nevertheless, this inevitably results in yet another opportunity for breaking the immersion.

VIII. Conclusions

The time has come for feasible technological solutions for a realistic haptic feedback, and the number of companies trying to take this opportunity is ever-growing but Dexta Robotics has an edge among them, with its presence going years back, and with its elegant solutions for a user-friendly device. HaptX is on another level, leading the technology and pushing boundaries, although remaining unapproachable for the masses, for years to come. In the meantime, more impatient VR fans are going to have to settle for motion tracked gloves with vibrotactile feedback, but without the force feedback exoskeletons.

References

[1] J. Perret and E. Vander Poorten, "Touching Virtual Reality: a Review of Haptic Gloves," in ACTUATOR 2018; 16th International Conference on New Actuators, pp. 1–2.

[2] UploadVR. "HaptX Gloves: More Realistic Touch Sensations For VR's Future - UploadVR @ CES," *YouTube*, Jan. 10, 2020 [Video file]. Available: https://www.youtube.com/watch?v=0Lgyvr7vsJs. [Accessed: Apr. 30, 2020].

[3] Adam Savage's Tested. "Hands-On with HaptX VR Haptic Gloves!," *YouTube*, Jul. 12, 2019 [Video file]. Available: https://www.youtube.com/watch?v=aEJWSPfFXmw. [Accessed: Apr. 30, 2020].

[4] SmarterEveryDay. "How do you make a Virtual Reality Glove? – Smarter Every Day 191," *YouTube*, Mar. 19, 2018 [Video file]. Available: https://www.youtube.com/watch?v=s-HAsxt9pV4. [Accessed: Apr. 30, 2020].

[5] Engadget. "Tactile sensation in VR with HaptX Glove hands-on," *YouTube*, Nov. 21, 2017 [Video file]. Available: https://www.youtube.com/watch?v=UaWZpRsyZ74. [Accessed: Apr. 30, 2020].

[6] Adam Savage's Tested. "PROJECTIONS, Episode 8: Hands-On with Dexmo VR Haptic Exoskeleton!," *YouTube*, Apr. 21, 2017 [Video file]. Available: https://www.youtube.com/watch?v=EAy6aRnUslY. [Accessed: Apr. 30, 2020].

[7] S. Jadhav, V. Kannanda, B. Kang, M. Tolley and J. Schulze, "Soft robotic glove for kinesthetic haptic feedback in virtual reality environments," in IS&T International Symposium on Electronic Imaging 2017, pp. 1–2.

[8] CyberGlove Systems. "CyberGlove Systems Haptic Workstation Overview," *YouTube*, Jul. 30, 2013 [Video file]. Available: https://www.youtube.com/watch?v=4aMCJDOEi0k. [Accessed: Apr. 30, 2020].

[9] CyberGlove Systems LLC. Internet: http://www.cyberglovesystems.com/cybergrasp, 2017 [Apr. 30, 2020].

[10] HaptX. Internet: https://haptx.com/, 2019 [Apr. 30, 2020].

[11] Dexta Robotics. Internet: https://dextarobotics.com/, 2018 [Apr. 30, 2020].

[12] Vivian Reed. "Nissan Design collaborates with HaptX to bring realistic touch to vehicle design" Internet: https://haptx.com/nissan-collaboration/, Mar. 08, 2019 [Apr. 30, 2020].

[13] M. Bouzit, G. Popescu, G. Burdea, R. Boian, "The Rutgers Master II-ND Force Feedback Glove," in IEEE/ASME TRANSACTIONS ON MECHATRONICS, VOL. 7, NO. 2, JUNE 2002

[14] Nathie. "Hands-On with Dexmo VR Haptic Gloves!," *YouTube*, Jan. 31, 2020 [Video file]. Available: https://www.youtube.com/watch?v=nHvbjiYjaXU. [Accessed: Apr. 30, 2020].