# Haptic technologies for the metarverse

Nathan Poret
nathan.poret@viacesi.fr
Cesi Student FISE SPE INFO

Valentin Pain
valentin.pain@viacesi.fr
Cesi Student FISE SPE INFO

Benjamin Brifault
benjamin.brifault@viacesi.fr
Cesi Student FISE SPE INFO

Arthur Lecras
arthur.lecras@viacesi.fr
Cesi Student FISE SPE INFO

Dove-Steeve Bingo Kpognon
dovesteeve.bingokpognon@viacesi.fr
Cesi Student FISE SPE INFO

Pierre Garrido
pierre.garrido@viacesi.fr
Cesi Student FISE SPE INFO

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**Abstract**

This document is a state of the art of environment virtualization technologies. The technologies represented will initially be virtual reality, augmented reality and the Metaverse. The latter will be the focus of the technological research. Indeed, the main question of this document is particularly focused on the technologies related to the Metaverse.

## 1 Introduction

The era of virtual reality has begun. The human senses are beginning to be immersed in another world. Today, the simulated senses are sight and hearing. In addition, other simulation of senses are being developed, such as touch. However, many haptic technologies exist and a choice among them is necessary to perceive which technology will provide the best experience to the user.

## 2 Main question

*How do you give a user the best haptic experience possible?*

## 3 State of the art

### 3.1 Augmented Reality, Virtual Reality, and Metaverse

#### 3.1.1 Augmented Reality

According to the booklet, "The-Concise-FINTECH-COMPENDIUM" by Patrick Schueffel, p.2: "Augmented reality is an enhanced version of the physical, real-world reality of which elements are superimposed by computer-generated or extracted real-world sensory input such as sound, video, graphics, or haptics.". So, augmented reality (AR) simulates an additional sensory to the user while that user is getting its normal sensory input from its surroundings.

AR requires a device with a camera and AR software, such as a smartphone, tablet, or smart glasses, to overlay digital material in a real-world environment. To process the video stream captured by the camera and distinguish objects in the environment, the AR software uses computer vision. Computer vision is a branch of artificial intelligence (AI) that allows computers and systems to extract useful information from digital images, videos, and other visual inputs, as well as to conduct actions or make recommendations based on that data. This enables the AR system to project virtual content in a precise place. The digital content is then realistically shown on top of the real environment via the display device.

Two main types of AR exist: marker-based AR and marker-based AR. Marker-based AR applications use physical images captured by the camera to place digital content on top of them. Logos, posters, and QR codes are different types of markers. Markerless AR works without markers and allows users to choose where the digital content is displayed. To obtain information about the environment, Marker-based AR applications use the device's camera, GPS, compass, and accelerometer. Markerless AR uses three different methods: Superimposition-based AR, Projection-based AR, and Location-based AR. Superimposition-based AR recognizes items in the actual world and partially or completely replaces their original perspective. Location-based AR works in specific places. The virtual object is positioned at the point of interest using the device's GPS and compass. Unlike the previous methods, projection-based AR does not require a display device to display virtual objects, but instead projects light onto a surface to do so.

#### 3.1.2 Virtual Reality

Virtual Reality (VR) uses computer technology to build three-dimensional artificial environments that people can interact with. VR technology allows users to be immersed in virtual experiences rather than flat-screen digital experiences using special equipment such as headsets. Unlike AR, which adds virtual objects to the real world, VR provides a more immersive experience and completely simulates an environment.

Virtual reality technologies deceive the human brain into viewing the virtual environment as reality by replicating as many senses as possible. Special hardware components are used to achieve this. The main component is head-mounted displays (HMD). HMDs are used on headsets and provide a three-dimensional picture of the virtual environment. It simulates human eyesight with a field of view and a frame rate. Another important component are headphones. Headphones provide realistic audio of the environment that matches what the user sees from HMD. To track and adjust the virtual environment, gyroscopes, accelerometers, and magnetometers are used. They look at the position and the direction of the user's head in the room to transcripts them in the simulation. Users can interact with the virtual world using controllers, gloves, treadmills, etc, and can stimulate other senses such as touch.

The experience of VR can be fully or semi-immersive. A fully immersive VR is the experience that gives the most lifelike experience. It involves all the components used for simulating a sensation, the user is completely cut off from the rest of the real world. The main difference with the semi-immersive VR experience is that the user is not completely isolated from reality and remains connected to their physical surroundings.

#### 3.1.3 Metaverse

The term "Metaverse" first appeared in 1992 in the novel "The Virtual Samurai", written by Neal Stephenson. The world described there is a science fiction universe, which could be close to our future reality. The article “Metaverse” by Stylianos Mystakidis gives the following definition: “The Metaverse is the post-reality universe, a perpetual and persistent multiuser environment merging physical reality with digital virtuality. It is based on the convergence of technologies that enable multisensory interactions with virtual environments, digital objects and people, such as virtual reality (VR) and augmented reality (AR).” However, since multiple brands have their Metaverse, there is not one Metaverse but multiple Metaverses. So, the definition is the same but must be more general, using like “a Metaverse” and not “the Metaverse”.

### 3.2 Haptic technology

#### 3.2.1 Origin and Definition

The skin is an extremely complex organ of the human body. In the world of virtual immersion, the sense of touch is essential and allows a more complete immersion of the human mind in a virtual environment. This is why haptic devices are becoming more and more important in virtual immersion technologies.

A haptic device allows communication between a human and a virtual environment, such as virtual reality or the Metaverse. Also called a tactile-kinesthetic system, this device is used to design and manipulate objects (in this case, clothes) with tactile feedback. Video game controllers are equipped with these devices, which allow the controller to produce vibrations related to events and actions in games.

For a haptic device to work properly and perform well, it must ideally meet 3 conditions:

- Transparency: The user of this device should not feel it being used. The customer should not feel the weight of the device or the friction of the device when handling it.
- Position resolution: This device must be able to detect the slightest movement of the user to be able to transcribe it correctly in the virtual world. If this transcription is not perfect, the user could have the sensation of touching an object in the world with the device without actually reaching the object in the virtual world.
- Stability: This condition represents the performance of the device to reproduce the sensation of touching an object. Therefore, this condition is essential to develop a haptic device.

### 3.2.2 Different haptic technologies

Haptic technologies based on vibrations are the most used in the industry today. The sense of touch can be simulated by vibration, electricity, sound, or heat.

The vibrations are produced with the "Eccentric Rotating Mass" (ERM) technology. This technology is the most widely used to simulate vibrations today. The ERM rotates on itself and when its speed increases, the weight of the eccentric mass becomes unstable and drives the motor in a rotational movement. It is this movement that produces the haptic feedback in the form of vibration.

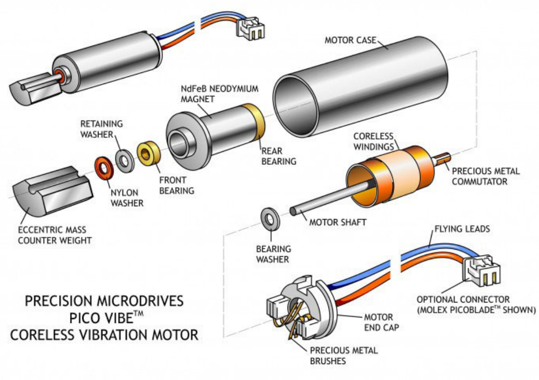


Figure 1: Eccentric Rotating Mass (ERM)

There is also a second technology producing vibration, "Linear Resonant Actuator" (LRA). This technology is more recent but is already used in some game consoles like the Nintendo switch for example. The LRA is composed of a magnet and a spring wrapped in a coil. Once powered, the coil forces the magnet to move back and forth inside. This movement also produces haptic feedback in the form of vibration.

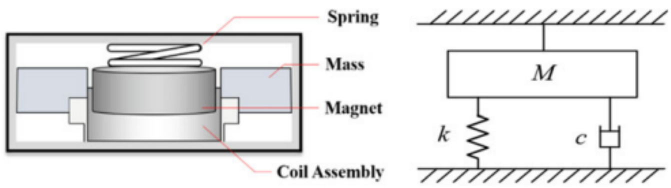


Figure 2: Linear Resonant Actuator (LRA)

Another vibration technology is the piezoelectric actuator. The elementary principle of the piezoelectric actuators is the inverse piezoelectric effect. It can produce deformation (mechanical stress) when an AC electric field to a piezoelectric material is applied. This deformation is proportional to the intensity of the electric field. Polymers are commonly employed in piezoelectric-based force touch-sensing devices due to their excellent mechanical characteristics. However, ceramics are commonly used in haptic applications due to their high piezoelectric coefficient. To transmit the force created by the inverse piezoelectric effect, one side of the piezoelectric material is attached to the mass block. To keep the system stable, the other side is joined to the fixed baseplate. The haptic feedback can be done by using a high voltage (200 V).

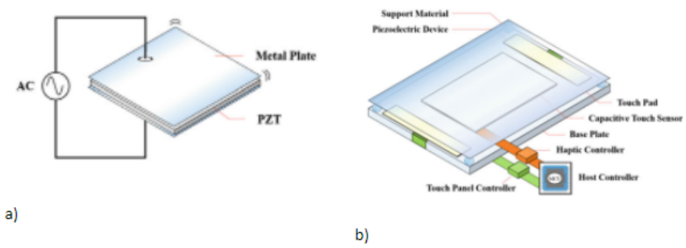


Figure 3: Piezoelectric actuator

(a) A typical piezoelectric actuator structure ;

(b) A commercial product of capacity touch panel with a piezoelectric actuator by Kyocera Corp with an architecture of 30V.

This technology provides a short startup time (less than 5 ms) and can reach the programmed acceleration in a short amount of time. When the driven power is used, it consumes less power (from 0.1 to 1 W). It is possible to create a more complex haptic effect, by controlling separately the position and the vibration frequency. Moreover, the frequency response range is broad, allowing users to receive the most complete and realistic haptic sensation possible. However, a high driving voltage is necessary (about 200 V for four-layer piezoelectric materials) and the poor boosting efficiency (35–57%) creates significant circuit heating, necessitating the installation of thermal protection for the chip in long-term operation. It requires additional components, and the materials used for PZT are fragile and so easily breaks. And finally, this technology is expensive.

In 2010, Pacinian Corp. introduced a new vibration technology: the surface actuator. This technology distributes between two plates' positive and negative charges uniformly and use a spring to limit the movement scale. With that technology, it is possible to create overall vibration over a vast area plane, users can get keystroke-like effects. On the touch screen, a consistent response can be produced. Also, the system reaction time range is broad, spanning 0 to 500 Hz. There are no additional actuators necessary to generate vibrations because they are integrated with the touch screen. However, the operating voltage is higher than in previous solutions and mass production is still a long way off.

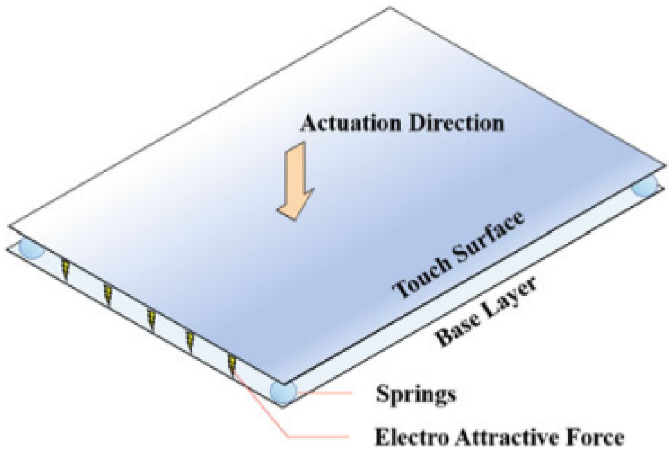


Figure 4: Surface actuator

Electroactive polymers (EAP) use electric signal-induced mechanical displacement to provide haptic feedback. According to their activation method, EAP actuator's working mechanisms can be split into ionic- and electronic-based architectures. High haptic resolution displays have been made using EAP techniques. Each actuator in the display may be manipulated separately to change the display's height, transmittance, and flexibility. Because of its great effectiveness in providing displacements with high spatial precision, EAP techniques are also used for braille reading. It should be mentioned that EAP technology is still in development, and various challenges remain unresolved. EAP materials are sensitive to humidity, necessitating the implementation of a water-impermeable surface. Long-term use results in a heavy electrolyte loss phenomenon, which influences surface conductivity. A heat-resistant design is preferred to facilitate operation at higher voltages without destroying the material's internal structure.

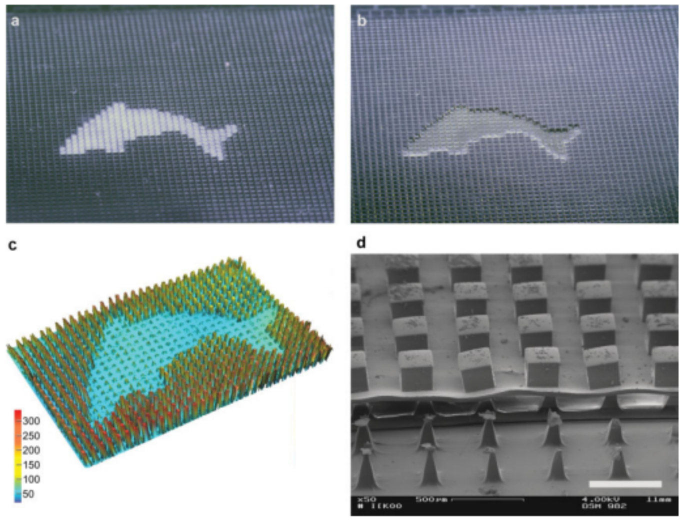


Figure 5: Generation of visual and palpable information by the "artificial skin"

(a) When the phase transition temperature is exceeded, the hydrogel immediately changes its color from transparent to opaque. The "artificial skin" displays monochrome visual information ;

(b) After finishing the shrinking process, the skin maps the sharp outlines of a dolphin. The length of the dolphin from mouth to tail is 14.5 mm ;

(c) The hydrogel actuator array maps the dolphin with sharp contours and single-pixel accuracy ;

(d) In order to improve the palpation of edges and outlines, a knob is placed on top of each actuator.

In 2009, Senseg Oy presented "E sense", the first capacitive electro-sensory interface (CEI) method. It uses a short-distance capacitive coupling mechanism to communicate conventional indentation to the skin.

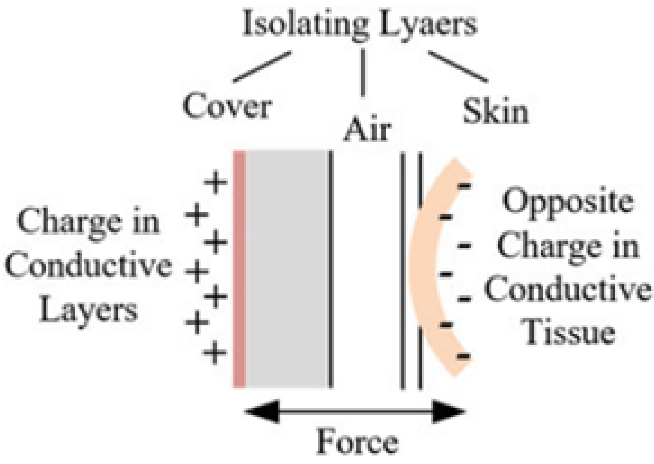


Figure 6: Working principle of the E-sense when the weakly conductive layer is embedded under the surface of the touch device

The conductive layer is charged during operation, and the coupling mechanism causes the opposing charges to accumulate on the finger that contacts the screen surface. These opposing charges will be attracted to each other by the Coulomb effect, producing a mechanical force. The vibrational amplitude and frequency can be modified to suit a variety of applications by modifying the polarity and quantity of the charges on the conductive layer and adjusting the frequency of the driving voltage waveform. CEI has some benefits, the vibration feedback's frequency, strength, and roughness can all be adjusted independently. Also, the finger can hang in the air and communicate both pressure and touch using the principle of short-distance capacitive coupling. However, the effective vibration range is tiny. Also, under sweating conditions, the vibration performance is considerably reduced.
In the article by M.Marchal 2020, it is demonstrated that focused ultrasound haptics can provide the sensation of interacting with objects of different stiffness. Indeed, focused airborne ultrasound (very high intensity and focused mechanical wave) is the most advanced technology to provide airborne haptics. In this paper, the experiment was performed with an Ultrahaptics STRATOS platform, which is a commercial focused ultrasound array. An HTC Vive tracker was attached to the participants' dominant wrist to track their hand movement, and a virtual hand avatar mimicked this movement in the virtual environment. In fact, the purpose was to demonstrate the contact ultrasound method of control. This can detect the stiffness of a surface and scan large surface defects such as delamination.

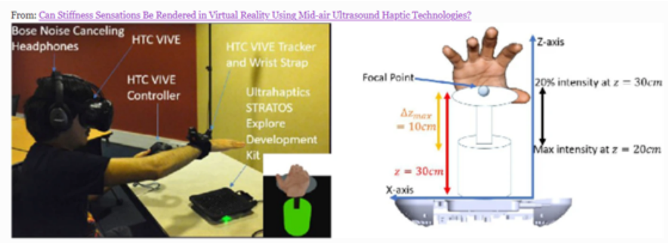


Figure 7: Ultrasonic technology

Electrical muscle stimulation, also known as electrostimulation, is a technique for stimulating muscles through electrical impulses of varying degrees. Indeed, when the muscle receives a dose of electricity, it contracts and sends information about its condition to the brain. Thanks to this method, first used in the medical field, it is possible to simulate a virtual environment while having haptic sensations linked to the virtual actions carried out by the user.
The sending of electric current to the muscles is done thanks to electrodes simply stuck on the skin.

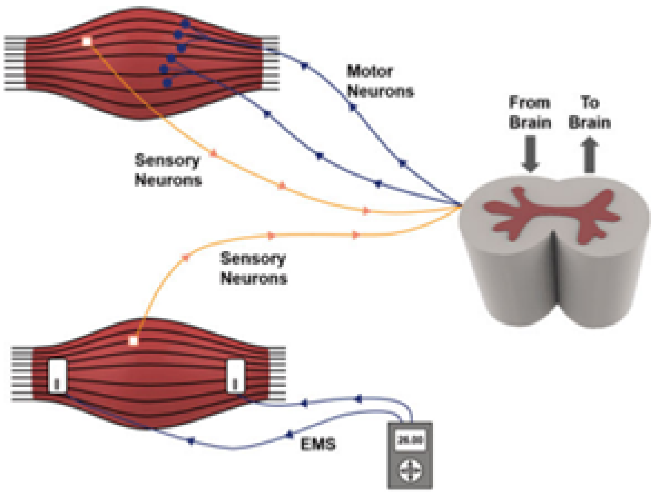


Figure 8: Electro-Myo-Stimulation (EMS)

The study on bioelectrical stimulation published in Shuo Gao's book shows that the bioelectrical stimulation technique can improve the performance of the interaction between the man and machine. Indeed, the haptic feedback results in the activation of the muscles by the electrical pulses. In addition, the biological study that benefits the development of functional electrical stimulation shows the composition of the sensory receptors of human fingers. In fact, the so-called Axon receptors are of the fast-adapting type, the slow adapting type I and the Pacinian corpuscle. These different cells have well-defined functions. The fast-adapting axons are the closest to the superficial skin and the slow-adapting type I is the second closest, while the Pacinian corpuscle is the deepest. Indeed, the axons are stimulated from the inside and outside as the potential inside the axon is relatively stable, the activation force is directly associated with the potential outside. In addition, this technology uses electrodes to inject current through the skin, and at the same time generates pressure and vibration sensations to achieve haptic feedbacks.

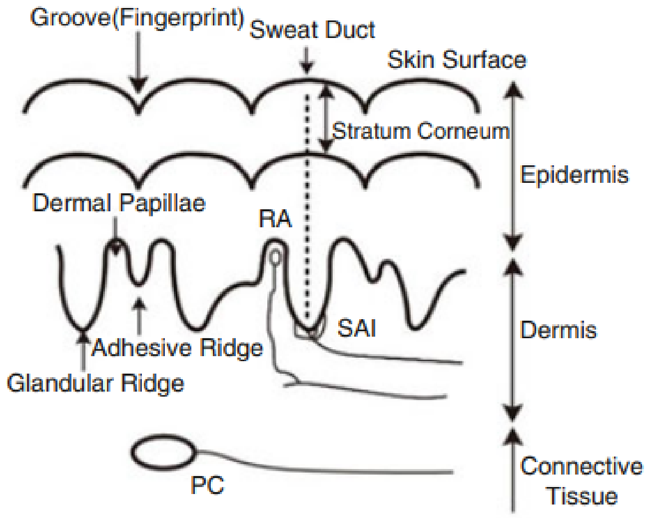


Figure 9: Functional Electrical Stimulation (FES)

In the article from techxplore written by Steve Kuhlman the 3 March 2022, the research team explains that a feeling provided by the friction during a contact with a touchscreen can be modified by changing locally the temperature. So, they will be able to reproduce some texture like “the skin of a snake” or “fabric of clothes”. They explain that there is a unique couple of mechanical and thermal sensations associated with a specific texture. The application domains are very varied and are very interesting for the Metaverse. They didn’t give any details about how it works because the research is just starting, many difficulties still remain as well as things to discover. For example, the miniaturization and the integration for touchscreens will be a great challenge!

## 3.3 Ethics in the Metaverse

Advances in virtual reality technology allow for a more immersive, realistic, and better experience of the Metaverse. The Metaverse uses data collected in the real world to offer immersive experiences. This virtual universe that this new technology offers, gives the possibility to be in a world that is closer and closer to the real world. With the appearance of haptic technology, users can interact with other assets and virtual avatars. A haptic virtual reality suit allows users to feel physical contact sensations all over their body while immersing themselves in virtual reality. However, the relationships and social interactions can be valuable in inferring users’ habits, activities, and choices in the Metaverse.

The reality devices that the Metaverse incorporates can therefore capture a large amount of information, from users’ biometric data to spatial data, including environments such as the physical space around the Earth. It goes without saying that a real ethical problem arises.

The approach of recent activities conducted on the ethical issue of the Metaverse reveals concerns related to the vulnerability of certain groups of people, the interactions between users, the aftereffects of the consumption of haptic technologies, the confusion between real and virtual, data issues, the Metaverse as an interface to inflict physical harm, and the potential psychological and social implications.

Indeed, the framework and level of freedom are not yet clearly defined, so privacy is at risk. The Metaverse can collect certain biometric data and the various movements made, preferences, places visited... that are not obvious to users. The collected biometric data endangers the most personal aspects of our existence.

Moreover, as we have noted earlier, liver technology allows sensory feedback. This poses a huge ethical problem because any virtual contact is reflected in the physical body. Indeed, the sensors attached to the users can realistically control their avatar. The Metaverse cannot control the psychological state of the users, so the users are not safe from virtual aggression on the avatars, which reverberates on the physical body.

The development of more and more realistic virtual worlds with the concept of the Metaverse allows us to use the advances of the technology, including the sensory return with the haptic technology. This technology creates an ethical problem, essentially based on privacy. It collects biometric data to make the user’s experience in the Metaverse more realistic.

In general, the Metaverse can easily become an ethical problem in the management of personal data.

The increase in realism by the Metaverse technology can be explained by the rise of personal data acquisition through haptic technologies. To improve the movement’s fluidity of the avatars, it is necessary to activate others useful functionalities, like the location of the user in his room and the motor actions to virtually reproduce the movement. Many more information can be recorded such as traits, motor actions, eye movement patterns, reflexes, preferences and habits (Spiegel). This type of personal data cannot normally be collected by current products or experiences without this technology being integrated into current consumption patterns. New ways of thinking are therefore needed to address the collection of data specific to haptic technologies.

# 4 Hypotheses

- Touch can be simulated at the neural level by mimicking the electrical information sent by the muscles to the brain ;
- Technologies using a haptic combination will be the most feasible solutions for the end user ;
- In order for a haptic suit to work, it must have as many sensors as there are muscles ;
- It is possible to simulate haptic sensations via a device placed on the back of the neck (above the spinal cord) ;
- The sensation of touch can be simulated by a box filled with a fluid and sprayed with ultrasound ;
- Adapting the anti-gravity suit of aircraft pilots into a haptic suit is a haptic technology solution ;
- It is possible to disrupt a user's inner ear by producing different sounds that allow the user to experience haptic sensations ;
- The sensation of touch can be simulated using thermal and mechanical sensation to imitate textures ;
- To enable the development of a networked haptic solution, the data transmission of the haptic technology must consume as little bandwidth as possible.

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