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HAPTIC INTERFACES: KINESTHETIC VS. TACTILE SYSTEMS

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1. INTRODUCTION

The haptic sense complements the sense of vision, because it allows the obtaining of information from other physical characteristics. As such, it supplies major details of the object with which a user interacts through movements of exploratory activities. (Do et al., 2012).

The term haptic (from the Greek *háptō/ haptesthai* (touch, relative to tact)) is the adjective used to describe everything related to or based on the sense of touch. It also makes reference to the science of all that is relative to tact and its sensations as a means of control and interaction with machines and computers (González, 2011)(Genoy Muñoz et al., 2011). The information from the haptic sense comes from the active and voluntary manipulation of objects in the environment made from fingers and hands and involves the sense of tact and the perception of the body's movement known as kinesthesia (Cortés et al,. 2010). In general, for the manipulation of an object, the tactile aspect refers to the static and the information received from the nerve terminals of the skin. Kinesthetic, meanwhile, refers to the dynamic aspects of said interaction with the object (Carter & Fourney, 2005).

Consequently, a haptic interface (HI) is a device which is in charge of reproducing in the user what is captured from the sensation of contact and manipulation of an object that is found within a virtual environment or remote setting, simulating the essential characteristics of tact and holding of a real object, such as temperature, texture, weight and shape, among others. (Golledge et al., 2006) (Hernantes et al., 2012).

A number of considerable haptic devices exists which allow users who are apart to exchange information through the sense of tact. This information can be perceived from inanimate objects or controlled devices (Rantala et al., 2011).

The haptic sense encompasses two types of sensations which produce information about an object and are useful for the interpretation the human brain makes of this. It has to do with the perceived trait of the manipulated body. If it is its mass, it provides information about the weight and inertia. An idea is developed by means of the kinesthetic sense through receptors located in the muscles, joints and tendons. These receptors also allow the person to feel the force/torques exercised upon contact with a body and to know where this person's hand is within the space, even with his eyes closed (Coles, 2011). From the physiological

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point of view, the kinesthetic has to do with being conscious of the position and movement of the body within the space. It is the part of the somatosensory system that is conscious of the perception of the body and is distributed throughout the entire body (Fogtmann et al., 2008). If the stimulus is texture, temperature, pressure or vibration, it is directly related to cutaneous or tactile mechanical receptors situated in the skin (Chen et al., 2006). The hairless skin (hands, lips and feet) is the most responsive to tact with respect to body parts that do have hair (Nakamura et al., 2003).

Analogously, HIscan is divided into two main groups from the point of view of the sensation they can produce at the moment of contact with the part of the body, those which produce kinesthetic stimuli and those which produce tactile stimuli. Various developed HIs exist, as well as others in the research phase (Bilgincan et al., 2010)(Ferre et al., 2008). This first type of interface points toward stimuli of the force of extremities (hardness, weight and inertia) (Vélez, 2011), being complemented by algorithms of haptic rendering which calculate the forces of interaction between the device and the virtual objects it manipulates (Nájera & Díaz, 2005). The second type is focused on an actuator which stimulates the skin in any zone of the body, applying signals of temperature, vibration, pressure or coarseness, among others (Vélez, 2011).

The degree of realism to which the user perceives the stimulus the virtual object recreates is in great measure due to the technology employed by the device with which he interacts, the type of actuation upon the human body (kinesthetic or tactile) and the complementary action of an algorithm-program to help the recreation of the stimulus (Lim et al. 2014). As such, the specificity and degree of realism that these haptic devices found in the market have will influence in the purchasing costs, the end user and the type of application.

The development of this article stems from observation and is supported on the state of the art in order to demonstrate a tendency in the combination of kinesthetic systems with tactile systems in order to achieve greater realism of the perception of sensations. It also intends to pose an analysis of this phenomenon. Section 2 presents characteristics of kinesthetic systems including their main function, historical evolution, commonly used technologies for construction and specific cases. Section 3 presents an analogical development of tactile systems. Section 4 presents the state of commercial dissemination of both systems. Section 5 shows examples of combining both types of existing interfaces. Section 6 poses a discussion, taking into account the posed information in the previous sections. Finally, section 7 presents conclusions.

2. KINESTHETIC TYPES OF HI

Akinesthetic HI acts on the active aspects of tact (understood as information acquired by means of movements and/or the force in the muscles and joints)(Carter & Fourney, 2005).

This entails a feedback of forces on the part of the kinesthetic HI and occurs because of the exchange of forces between the user and the virtual environment in which it is found. In order to achieve embodiment, the interface should be capable of affecting the body or body part in contact in order to simulate the weight of objects lifted (Bergamasco & Ruffaldi, 2011). This principle and its improvement are optimized to the maximum in the development of serious games and rehabilitation processes with robot type haptic-kinesthetic devices (Bouri et al., 2013).

The technology used by the kinesthetic interfaces looks to exercise the feedback of the control's force over the body part, normally fingers, palms of the hand or arms, to recreate the object (Bergamasco & Ruffaldi, 2011). This entails its active principle to be of the electro-mechanic type and can be achieved via various methods, using metals with memory for forms, electric motors in continuous, pneumatic cylinders and magnetic actuators in conjunction with different mechanical rigs, such a joints, bands and cables that transfer the forced produced and focalize its effect specifically on the user's extremity (Youngblut et al., 1996).

The kinesthetic or force feedback HIs show behaviors similar to robot mechanisms with which the user interacts and exchanges mechanical energy (O'Malley & Gupta, 2008). These take into account the Degrees of Freedom, DOF with which the user can move using the device, which incurs greater naturalness in the interaction. Three degrees of freedom implies that movement can be in three dimensions but upon increasing the amount, the repercussion is the decrease in the restriction of movement, giving greater capacity to the work space and an increase in the naturalness of the execution of the interaction. The 3 to 6 DOF kinesthetic HIs are the most disseminated due to the fact that in both mechanical aspects, as well as programming, they are relatively simple to develop, go hand in hand with low production costs and are versatile in handling (ElSaddik et al., 2011).

The HIs should take into account the given functional limitations for balance between the design and versatility in its performance, that is, a major work space will require greater length of the elements, greater material resistance, commonly metal, which will make it heavier, thus increasing inertia while decreasing rigidity of the interface (López et al., 2011). Likewise, the greater the number of joints will also make it voluminous and complicated to control. If this well offers design challenges, currently designers have opted for the implementation of pieces made up of new materials based on carbon, such as polymers and other compounds (O'Malley & Gupta, 2008), as well as a strategic combination with metal which will allow rigid and light designs.

Another aspect which characterizes a kinesthetic HI is the portability it has. There are ones for desktops (joysticks) and according to the anchor type or support, they can be portable or fixed. Portable types are mounted and attached to the user's body, which means the user can move his body and extremities and move about. This means there will be a relative reference to the exerted forces. The other type of anchoring is one in which the interface is attached to a base embedded into a fixed place, be it a desk, floor, wall or ceiling, which means the user must be located in a specific spot and generally move only the extremity attached to the interface (Sabater 2003).

The type of final effector placed on the fixed interface helps the realism which is enabled in the interaction with the virtual or physical environment it has. In the case of the human hand, an interface effector type scissor or clamp that is held with two or more specific fingers, as well as the muscles involved, are very different to one of another interface in the shape of a pen or similar instrument, such as a scalpel (Wagner 2014).

The way the kinesthetic HIs are mechanically built is defined under two great categories related to the way the force feedback is applied (via links and tension elements). The first are small in size and portable, while the others are large. The most commonly used interface is the linked element one, where the rigid elements are linked among each other until the final effector and are activated by electric engines situated at the base of the device. This programming provides a good transmission and tracking of force toward the final effector. The force of the motor will be greater as the weight and length of the link increase. Also, position decoders of greater precision will be required if mobility is needed in a reduced work space (Coles 2011). Examples of these are Novint Falcon (Novint 2012), Geomagic (Geomagic 2015) y Phantom (Sensable 2016).

The second interface group has, as principle, the transference of force through tension cables, that is, that by means of pulleys and guides the final effector receives the exerted force via motors in continuous and its movement is graduated by movement via digital decoders connected to them. The example of this type of interface is SPIDAR (Sato 2002), basic and subsequent models. In this example, the elements are mounted on a cubic or cylindrical structure and, on it, the motors are distributed, one above, one below, tensioning oppositely, with cable support at the corners. In the central part of the workspace, a balanced effector is suspended in order to support the finger or the hand and it is tensioned according to the interaction undertaken. With this design, from one to six degrees of freedom are allowed and it can be inferred that the greater the number of cables, the greater the fidelity in the exerted force (Coles, 2011). This device has escalated to average dimensions of an adult person for diverse applications in education and design (Naud et al., 2009).

In this second group, a haptic exoskeleton is also found. This is another type of interface for the transference of force that was developed some time back and is based on tension cables by motors and position decoders. The support for these devices can be on the floor, wall, desk or on the user's body and can achieve more than six degrees of freedom in the workspace (Sabater, 2003).

There are commonly existing attachment systems in hands and fingers (Torres, 2012) or arms (Sledd & O'Malley, 2006) and their application also extends to the rehabilitation and ergonomic fields. For example, the exoskeleton that is attached to the arm looks to reproduce grabbing and attachment by means of the support of hand forces and two or more fingers. Examples of commercial exoskeletons are the Cybergrasp (Cyberglovesystems, 2015a) interface and the HIRO III (Robothand, 2015) interface.

There are kinesthetic HIs that use a feedback of force principle different from the classic techniques and methods. An example is the kinesthetic interface type whose function principle is by means of strong magnetic camps, employing the Lorentz levitation principle for the interaction of forces (Berkelman & Dzadovsky, 2010), such as how it is materialized in the Maglev 200™ commercial system (Butterfly-haptics, 2015).

Table 1 summarizes common technologies used for the development of kinesthetic HIs (Ueberle, 2006).

TABLE 1. SUMMARY OF TECHNOLOGIES APPLIED IN KINESTHETIC HIS

Technology	Actuator mechanism	Contact zone
Pneumatic	Piston	Direct support to extremities
Hydraulic	Piston	Direct support to extremities
Electric	DC motor directly connected or by cables and pulleys	Arm, hand-wrist or fingers
Magnetic	Lorentz principle levitation mechanism	Hand, fingers

3. TACTILE TYPE HIs

The tactile type HI, also known a touch screen, is a device that is in charge of stimulating the nerve receptors of touch to display, in the interaction with the human skin, parameters such as temperature, coarseness, shape and texture. The mechanical receptors which are commonly stimulated in touch screens and achieve contact simulation in the skin are those of vibration and pressure, since Merkel disks are activated with pressure and Meissner and Pacini corpusclesare activated with a low vibration or high frequency, respectively(Chouvardas et al., 2008). It has been demonstrated in various studies that tactile feedback in the tips of fingers has the potential for increasing the degree of immersion of the user in virtual or remote environments (telepresence and tele-operation) (Garcia-Hernandez et al., 2014).

There have also been developments of electro cutaneous interfaces using the principle of electro-stimulation of the nerve endings on the surface of the skin. These interfaces tend to be small, durable, efficient and the are free of mechanic resonance (Kajimoto et al., 2004)(Sato & Tachi, 2010). This method of electro-tactile stimulation can produce a wide variety of sensations in the skin from a light tickle to painful blows, as long as the frequency and amplitude of the applied pulses are varied (Pamungkas & Ward, 2015). Electro static interfaces which recreate the sensation of friction by generating normal forces between the skin of the finger and the screen have also been implemented. These generated forces are similar to condenser plates (Xu et al., 2011).

To stimulate contact by pressure, generally large scale devices are used that contrast to the small portion of skin over which they act, for example, the tips of fingers. The active stimulation principle technology is materialized in large dimensions, because of the quantity of active elements that an elevated power consumption entails and occasionally makes portability difficult. An example of this appreciation may be evidenced in interfaces for one finger that generate a Braille type stimulus, which use power units to drive needles or pins (Wagner et al. 2004) and others that employ a tactile matrix, driven in an initial development by a fixed ball that is transferred in two dimensions and, in a second development, by pneumatic effect with three bits of resolution (Benali-Khoudja et al., 2004).

To stimulate texture, small electro magnetic devices are used, such as inertia vibrator-resonators, linear resonator actuators (LRA) and eccentric rotating mass (ERM) motors (Yang, 2013)(Wang, 2014), as well as impact LRA motors (Pyo et al., 2015), medium-sized motors, such as voice coils(Richter et al. 2011) and some large ones that offer greater resolution, such as graphic touch screens based on needle matrixes activated by solenoids (Simeonov & Simeonova, 2014), drive units (Wagner et al., 2004) or that use long bars of dimorphic piezoelectrics in a Braille type interface by means of new pneumatic valves that work as an active or inactive bi-stable, which stay in one position and produce a protrusión by the continuous output of air under a membrane and upon deactivation closes the airway, which is why the protrusion disappears (Russomanno et al., 2015).

In general, the tactile stimulus can be obtained in various ways and the technologies that have been commonly used to generate them are pneumatic, solenoids, piezoelectric resonators, voice coils, form memory wire, motor tension bands and heat pumps, among others. Said technologies are summarized in Table 2 (Pasquero, 2006), taking into account that there have been no significant changes to date.

Additionally, it is important to consider other characteristics of design in the development of other tactile interfaces. Some types of actuators involve concepts of low energy consumption, for example, those with a ceramic piezoelectric sheet, mono or multi-layer (Poupyrev et al., 2002). Other developments contemplate the adequate location of actuators on the surface of the skin, secretions and the touch. Likewise, the fact that there must be a refresh-update of the tactile print made at a rate of 1 KHz (Pasquero & Hayward, 2003) or a close lesser value (690 Hz) that is practical and effective according to the application made is an important design consideration (Lévesque et al., 2012).

Tactile HIs have had developments which tend to find a balance between cost, portability of devices and the sensation produced. In this sense, there have been promising designs that point to portability, reduced size, that directly attach to the finger, which prints a contact stimulus to the tip of the finger by means of a mobile platform, which moves with respect to support and offers the sensation of contact with an arbitrarily oriented surface, with 2 DOF (Yazdian et al., 2013) and with 3 DOF (Chinello et al., 2015).

Taking into account all of the above, the development of tactile interfaces has been slow and the systems developed since the beginning have been voluminous, added to this, some lack the necessary portability to adapt to an HI of force to create a complete haptic feedback (Coles et al., 2011). Others are costly and frequently optimized toward one sole characteristic of the reproduced sensation, for which if a more realistic performance is desired, the device must comply with a set of requirements that will allow the providing of a variety of sensations to the user (Pasquero & Hayward, 2003). The analysis of characteristics of the current tactile HIs shows that those that provide very good resolution are voluminous and show usability limitations (Fontana et al., 2012).

This appreciation may be evidenced in two recent devices that generate stimuli of texture and softness upon placing the tip of the finger. The first, a desktop device, simulates softness to the touch and is based on a band of elastic knit that is supported by two servomotors, which coordinated create a movement a if they turn the same way or a tension/relaxation sensation if they turn opposite ways (Bianchi & Serio, 2015). The second device has a vibration actuator over a disk in contact with the finger that is supported by a mobile structure that generates two degrees of angular freedom and one of transposition. This provides a movement that allows the sensation of a flat, curved and border surface (Perez et al., 2015). This device, although portable, is difficult to hold in two consecutive fingers.

Another device that uses the same principle of two motors and an elastic band is the one designed and constructed to simulate caresses in the forearm of the user. This device design contemplated the pleasure and displeasure of the sensation produced in the results and poses further consideration, as well, of the gender difference for the extraction of characteristics of the obtained signal in the test subject (Bianchi et al., 2014).

TABLE 2. SUMMARY OF COMMON TECHNOLOGIES FOR TACTILE HIs

Technology	Description	Sensation
Electrostatic (Xu et al., 2011)	Capacitor with Polimer isolation, formed fluid conductors of the finger that act as a sheet and en external electrode that acts as another sheet	Friction, reproduces cutting forces on the skin.
Electrocutaneos (Kajimoto et al. 2004)(Sato & Tachi 2010)	Electro stimulation is made on the skin to activate the nerve endings	Pressure and soft vibration
Vibro-tactile	DC Motor con eccentric mass subject to the gyration axis (Yang 2013). Linear Resonator Actuator (LRA)(Wang 2014). Linear Impact Resonator Actuator(LIRA)(Pyo et al. 2015).	Vibration by pulse or sustained
Vibro-resonance (Kyung & Kwon 2008)	Piezoelectric or parallel bars vibro-resonator	Vibration con resonance frequencies gama
Display temperature shift system (DTSS) (Ferre et al. 2008)	Calefactor put on a finger tip	Temperature changes
Pneumatic pressure	Pneumatic piston attached to the hand	Finger contact with surface or pattern
Solenoid	Electromagnetic piston	Pressure upon holding
Exoskeleton for multiple fingers	Frame that connects a pressure actuator to each finger	Grabbing force, pressure, sustained pressure
Direct finger pressure	Belt or sheet that adjusts or relaxes on the finger tip via one or various DC motors	Sustained contact pressure, gradual, vibration, curvature, border

Electro Active Polymer(EAP) (Bolzmacher et al. 2004) (Runyan & Blazie 2010)(Pei et al. 2009)	Chemically modified polymer for a physical stimulus to activate, given by an applied high voltage	Pressure sue to superficial bulging, coarse texture, surface patterns
Pressure needles	Set of needles moved by electromagnetic camp which simulates pressure and pattern for the Braille system Needles moved by Shape Memory Alloy(SMA) (Kontarinis et al. 1995).	Sustained pressure, soft pulses
Thermal	Based on a Peltier sheet that controls temperature which interface transfers to the skin	Warming of a reduced zone of the skin
Ceramic piezoelectric (Poupyrev et al. 2002)	Mono or multi/layer sheet of ceramic piezoelectric which oscillates for applied voltage.	Sustained vibration or pulses
Rheological fluid (Song et al. 2003)	Fluid which modifies its viscosity via the application of an electric or magnetic camp	Rigidity

A tactile HI pencil-like device known as UbiPen has been developed in which a vibration motor and a needle matrix as a touch screen have been grouped. Each needle is activated by a linear ultrasonic motor. This combination generates patterns of vibration and texture in the user's hand (Evreinova et al., 2014).

In development, there are tactile HIs with an active principle different from conventional ones which allow for the sensation of softness. Among these are the rheological fluid (Song et al. 2003), which is capsuled in a piston and, upon application of voltage, modifies its structure going from liquid to solid and thus opposes movement. The magneto-rheological fluid devices act similarly to the above but when subjected to a magnetic camp (Pasquero, 2006).

Another type of actuator that reproduces the sensation of soft contact due to pressure is made up of electro active polymer (EAP) (Matysek et al., 2009), which presents a change of volume when a high value camp in the order of kilowatts is applied. The EAP comes in gel form in a capsule for isolation (Bolzmacher et al., 2004). These actuators have also been applied to the activation of Braille type interfaces that reproduce in form (Pei et al., 2009) (Runyan & Blazie, 2010).

On the other hand, there are developing ultrasonic interfaces which generate pressure on the skin in form and distributed by means of wave fronts at an ultrasonic level, freeing the user to place any device in his hands (Iwamoto & Shinoda, 2005) (Hoshi et al., 2010). There is an interface that also works with the same pressure principle of air on the skin of the finger which is controlled by an opening closing of the air outlet (Bianchi et al., 2011). In addition, there are also water spout types which throw water under pressure to the finger when it passes by a determined area in order to simulate contact with an object represented in said area (Richter et al., 2013).

A derivation of the tactile HI that uses air pressure is the sliding sheet over air type. It gives the sensation of friction and is based on the placement of a sheet on which the finger rests on the vibrating surface. This sheet remains suspended on a cushion of air due to the ultrasonic vibration of the surface. The friction with the sheet will increase or decrease depending on the increase or decrease of the vibration (Yang, 2013).

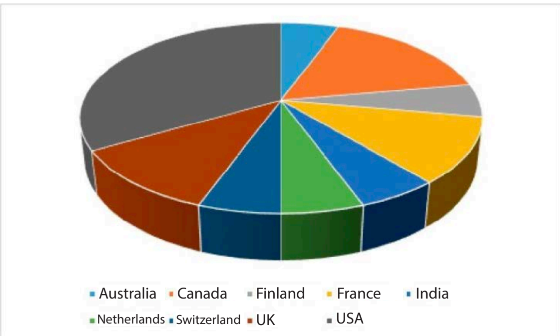
4. CURRENT COMMERCIAL AND TECHNOLOGICAL STATE OF HAPTIC INTERFACES

The development in haptic interfaces, both on a kinesthetic and tactile levels, have begun to go from labs to end users. In this sense, it is important to analyze the behavior of each one of the types of interfaces on a commercial level, as well as new proposals being developed from technical and commercial needs.

State of commercial dissemination of haptic interfaces

There are diverse companies in the world for the development of technologies for HIs in aspects such as programming (libraries and applications), electronic components, mechanical components, sensors, actuators and haptic devices, as such. In the current panoramic (Worldhaptics, 2012), a good number of companies exist, primarily in the United States, which are dedicated to the construction of HIs. Also, there is no participation in countries of Africa, Central and South America, as **Figure 1** shows.

Figure 1. World distribution haptic interface companies.
Source: author



These companies can also be grouped according to the most common types of development of simulation technology of the effect the HI has on the user and are classified into tactile-vibration, skin deformation, skin streching, electro-stimulation, thermal stimulation and kinesthetic, as **Figure 2** shows.

Figure 2. Simulation technologies for HIs.
Source: author

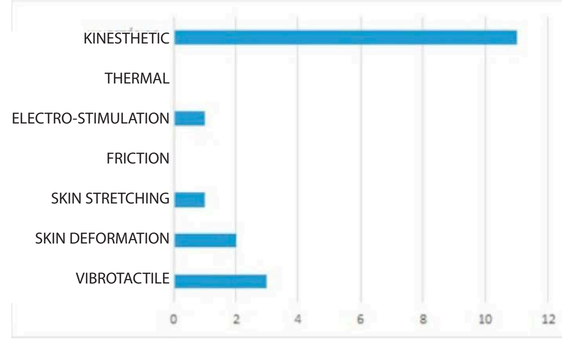


Table 3 summarizes kinesthetic HIs found in the market which have achieved greatest dissemination among users.

Table 4 presents a summary of the most disseminated tactile devices in the market.

5. COMBINATION OF INTERFACE TYPES

Both tactile and kinesthetic HIs have achieved a great development in recent years but each has taken its own path. The daily work experience in the haptic area has demonstrated that this division is neither effective nor intuitive since the simultaneous simulation of both tactile and kinesthetic is essential (Zeng et al., 2010). An object being explored with all the hand's fingers involves the stimulation of both proprioceptive receptors and skin mechanical receptors. The former are related to the follow-up of outlines and the latter are based on the pressure or distortion produced in the finger upon contact with objects (Frisoli et al., 2011). Knowing that said senses in the user can never be separated, it is understood that they are complementary or concurrent and are involved each time an object is being explored.

TABLE 3. SUMMARY OF KINESTHETIC HIs IN THE MARKET

Device	Company	Action zone	DOFs	Function principle and characteristics
PHANTOM (Sensable 2016)	Sensable	Hand, wrist pivot	6	Serial morphology, first degree of active freedom and the last three passive, position resolution 1100 dpi
Omni™ Bundle (Quanser 2016a)	Quanser	Fingers, hands	6	Hand movement and pivot of wrist, maximum force 3.3 N, work space160 mm x 120 mm x 70 mm
Quanser Haptic 3-DOF Planar Pantograph Blocks (Quanser 2016b)	Quanser	Hand	3	Planar hand movement subject to fist, driven by DC motors. Position and orientation of the final robot effector as a vector 3: coordinates X e Y in millimeters, and the orientation, θ, in radians
NOVINT FALCON (Novint 2012)	Novint	Fingers, forearm movement	3	Parallel morphology, work space 4" x 4" x 4", force 8.9 N, position resolution 400 dpi, automatic calibration
Thrustmaster TX Racing Wheel Ferrari 458 (Thrustmaster 2015)	Immersion	Hands	1	Steering wheel that provides force for driving maneuvers in car racing games
Haptic Master (Mimics 2015)	Mimics	Arms	3	Kinesthetic arm for rehabilitation with movement supported in a virtual environment
6 Dof DELTA (Forcedimension 2015a)	Force Dimension	Fingers, hands	6	Parallel structure, 20N, semi circle work space Ø 400 x 260 mm, rotation 22°, resolution 0.02 mm, USB 2.0, automatic calibration
CYBERGRASP (CybergloveSystems 2015a)	Cyberglove Systems	Fingers, hands	5	A degree of freedom for each finger 18 a 22 force sensors. Sensors to measure flection and abduction
HIRO III (Robothand 2015)	Robothand	Fingers	21	6 degrees of freedom in the arm and 15 in the hand sensation of force and tact in all finger tips, floor support
VIRTUOSETM 6D Desktop (Haption 2015)	Haption	Fingers, hand	6	Work space 521 x 370 x 400 mm, 270° x 120° x 250°, transposition maximum force 10N, rotation 0.8N, ethernet/UDP
OMEGA7 (Forcedimension 2015b)	Force Dimension	Hand	3	Parallel structure, 8N, USB 2.0, rotation 240 x 140 x 180º
Maglev 200™ (Butterfly-haptics 2015)	Butterfly Haptics	Hand	6	System which employs the Lorentz levitation principle for the interaction of forces
SPIDAR (Sato 2002)	Instituto Tecnológico de Tokio	Hand	3	Based on DCmotor, thin steel cables that reflect force in the final effectors. Contact with the object surface
SPIDAR G&G (Murayama et al. 2004)			6	3 degrees of freedom for transpositon, 3 for rotation and one for grasp - For two hands
7 DOF Haptic Interface (MPB 2014)	MPB Technologies	Fingers, hand	7	For one hand, scissors and sheet for index finger, work space transposition: 17x22x33 cm, 2.5N; P-Y-R: 170°-130°-340°, torque 370mN-310mN-150mN; scissors 40° a 450mN
DLR light-weight robot III (DLR 2015)	DLR - Robotics and Mechatronics Center	Hand	7	Maximum charge 14 Kg, Ejes R-P-R-P-R-P-P, maximum extent 936 mm, juncture speed 120°/s, torque sensor

TABLE 4. COMMERCIAL HAPTIC-TACTILE DEVICES

Device	Company	Contact zone with the body	Actuator	Stimulus	Tactile sensation
CYBERTOUCH (CybergloveSystems 2015b)	Cyberglove Systems	5 fingers and palm of hand	Vibrotactile	Vibration 0-125 Hz 1.2 N	Contact with objects
MI Mannequin Trainer (MerkelHapticSystems 2011)	Merkel Haptics	Hands	Vibrotactile	Simulation of vital signs	Allows the training of Cardio Pulmonary Resuscitation (CPR) techniques
HAPIfork (Hapi 2015)	Hapi Labs	Hands	Vibrotactile	Moderate vibration	Stimulus on the hand indicating it's quickly eaten
Lumo Lift (Lumobodytech 2015)	Lumo BodyTech	Chest hair	Vibrotactile	Moderate vibration	Stimulus on the chest which indicates when in bad posture, not erect
TACTUS Tactile Layer (TactusTechnology 2015)	Tactus Technology	Fingers	Tactile	Elevation of surface by means of fluid	Presence of button on touch screen for activation
Reactive Grip™ Motion Controller (TacticalHaptics 2013)	Tactical Haptics	Hand	Tactile	Stretching of skin Movement of sheets on the stick of the device in a coordinated way	Transmits information and force using tactile feedback integrated in the device stick
Senseg Tixel (Senseg 2015)	Senseg	Fingers	Tactile	Friction on finger by effect of Coulomb forces	Uses the attraction of charged electricity principle, on finger and screen which between each other make up a capacitor

This is why tactile and kinesthetic stimuli should be exercised in a combined manner. This situation is becoming the tendency in recent years' work, in which tactile interfaces are being adapted to kinesthetic interfaces and as a result, new techniques which adapt to the benefits of both systems are being implemented in order to achieve better performances, evaluated from different points of view.

A research project, which combines a tactile HI with a kinesthetic HI, was carried out for the remote palpation of textiles. This study grouped a tactile actuator of needles to a feedback of the force device which showed, via screen, the interaction of the user with the virtual fabric. The result, a perceived sensation of the texture and its inertia was achieved (Unige et al., 2008).

Another individual case for a tactile HI is combining with a kinesthetic HI which final effector is placed at a point in order to convert it into a tactile HI multipoint (Minamizawa et al., 2010). The same principle has been applied in the combination of one or two kinesthetic commercial interfaces focused on improving the stability in a tele-operation environment (Sarakoglou et al., 2012) (Pacchierotti et al., 2013).

There have also been individual cases of tactile HI application. One is to simulate to a certain point the feedback of the force. The method consists of coupling a stick type non acting manipulator which supports the hand and a tactile actuator on the fingers. The stick allows tracing the position of the hand, while the tactile actuator simulates the force of contact between the hand and the manipulator for the application of normal force on the tip of the fingers. The basis of this is that the tactile device refeeds the force in equal intensity and form on the contact area, as an active stick would (Pacchierotti et al., 2013) (Prattichizzo et al., 2010).

A new focus in the combination of HI types is one in which a device generates kinesthetic stimulus without mechanical links or floor references. However, these have the inconvenience of lesser resolution in the stimulus generated. A first example of this is a pencil shaped interface which has its base of reference in the hand and is attached to the finger, upon which a pressing stimulus is generated from the finger to the base, which simulates the object with which it interacts (Kamuro et al., 2011).

Another example of the implementation of said approach is for the mobile devices which are based on the technique of pseudo attraction force, in which a sensation of force is generated with a vibrating tactile stimulus by means of the combination of acceleration patterns in both directions in order to create the illusion of an unbalanced force (Amemiya et al., 2010).

6. DISCUSSION

Kinesthetic systems allow the interaction of force with an object, have the advantage of greater ease in their construction but do not achieve the perception of sensations of the surfaces of those. In fact, the kinesthetic interfaces reach the perception of an object in three dimensions carried out by the interaction of forces between the interface and the user by means of the virtual environment in which he finds himself (Bergamasco & Ruffaldi, 2011). The great display these interfaces have is due to the fact they are built with conventional technology (**Table 1**), which allows the development and commercialization with greater dissemination. The above is evidenced in the wide range of kinesthetic devices on the market (**Table 3**) and the presence of manufacturing companies in the first world (**Figure 1**) (Worldhaptics, 2012). Their applications range from rehabilitation tele-operation processes to the area of entertainment, validating their applicability and commercial advantages.

Tactile systems allow the greater definition of characteristics of the surface of objects because they work directly on skin receptors but the technological process of construction is more complex and increases the variables to reproduce.

The tactile interfaces are dedicated to reproducing contact with the skin by means of pressure, vibration (Chouvardas et al., 2008) and electro-stimulation actions (Kajimoto et al., 2004). With these, we can achieve the skin mechanical receptors creating sensations of texture, outline and rigidity (Bilgincan et al., 2010) (Ferre et al., 2008). This is achieved by means of diverse technologies for actuators which include DC motors, vibration resonants, needle matrix, solenoids and other more elaborate actuators of piezoelectric mono and multi/layer sheets, SMA memory wire, electro active polymers (EAP), electro rheological fluids (ERF) and magnetic rheological fluids (MRF), ultrasound and electrostatic, some of which are found in the stage of experimental development and perfectioning (**Table 2**) (Pasquero, 2006).

High resolution tactile interfaces have been achieved (Simeonov & Simeonova, 2014), which increase the level of realism that the user may achieve in a simulated environment but the construction of these interfaces is complex due to the dense distribution of the nerve terminations of the skin, which demands that the simulus be more zoned when applied. A consequence of all this is evidenced on the lesser quantity of developments if haptic interfaces placed on the market (see **Table 4**), in contrast to the amount of techniques proposed for the generation of tactile simuli (**Table 2**). As a complement, some technical difficulties appear regarding size and portability given that there is a desire to reproduce two simultaneous tactile parameters, results in low resolution of the effect produced by one of the stimuli (Fontana et al., 2012). This situation has been solved little by little and a point of equilibrium has not been reached.

When the same device has the benefits of a kinesthetic as well as a tactile interface, the greatest realism in interaction with the virtual-remote environment is obtained. The combination of the stimuli of the kinesthetic and tactile interfaces achieves better results due to the fact they complement one another and increase the sensation of reality to represent spacial texture and shape of the outline, as a flat or curved surface (Zeng et al., 2010). Upon combining a kinesthetic and a tactile HI, the fidelity in the interaction with the virtual/remote system increases and the perception of reality of the user improves, which potentially increases the level of remote/virtual immersion (Garcia-Hernandez et al., 2014). This is also evidenced in the decrease of orientation error in the tasks of PALPACION (Unige et al., 2008). The materialization of this fact has been easily made with the combination between a commercial kinesthetic interface and a tactile interface developed for a finger, with which satisfactory results have been achieved (Minamizawa et al., 2010) (Sarakoglou et al., 2012) (Pacchierotti et al., 2013). There is another type of interface wherein, by tactile means, simulated kinesthetic effects are achieved, without links or floor references. This is achieved combining the force/torque impulses that, applied to the hand's skin, give the sensation of object manipulation (Prattichizzo et al., 2010)(Kamuro et al., 2011) (Amemiya et al., 2010).

These final arguments evidence a perceived tendency based on recent years' developments, which by combining the effects produced by both types of haptic interfaces, the user's interaction with objects in virtual/remote environments produces a greater degree of immersion in the manipulation of those objects. In turn, there can be an improvement of useful aspects of individual tasks, such as the improvement of skills, the reduction of learning curves, as long as the system is being used as a means for learning a motor skill. This fact can be made extensive if applied with the perspective of the rehabilitation of persons with some sort of motor injury in upper extremities, like serious gaming is approached (Bouri, 2013).

7. CONCLUSIONS

There is a tendency to combine kinesthetic and tactile systems in order to achieve greater realism and immersion in the perception of senses in the interaction with objects within a virtual or remote environment. It is perceived that technologies used for the construction of kinesthetic HIs are more limited but at the same time more recognized, conventional and, as such, the most implemented. The tactile interfaces present great variety in form and technological construction but at the same time their development is, in the majority of cases, in experimental phases and not commercial, having aspects that need improvements and refinement due to the fact that the stimulus is directed toward nerve receptors located in the skin and in specific perception.

Evidence has been found that it is possible to achieve an ACOPLE of combined HIs making adaptations of tactile development to commercial kinesthetic interfaces, based on the fact that combinations of kinesthetic and tactile interfaces have been achieved which have allowed for satisfactory results in the representation of texture and inertia of movement, as well as the contact and manipulation of objects This combination of both types of HI has the potential to be used in multiple applications where the simultaneous identification of texture and outline is useful.

Regarding the aspect of the increase of the degree of immersion, work continues not only in tactile but also kinesthetic interfaces since they require adjustments, adaptations and a combination of new technologies for the improvement of the resolution, decrease of size and the portability of systems..

REFERENCES

Amemiya, T.; Ando, H.; Maeda, T. (2010). Kinesthetic Illusion of Being Pulled Sensation Enables Haptic Navigation for Broad Social Applications. In M. Hosseini Zadeh, ed. *Advances in Haptics*. InTech, pp. 129–134. [Online] Available at: http://goo.gl/bI6dOf.

Benali-Khoudja, M.; Hafez, M.; Alexandre, J.-M. (2004). Tactile interfaces: a state-of-the-art survey. *ISR 2004, 35th International Symposium on Robotics*, pp. 23–26.

Bergamasco, M.; Ruffaldi, E. (2011). Haptic Interfaces for Embodiment in Virtual Environments. *Proceedings of RO-MAN 2011*. [Online] Available at: http://goo.gl/mLO8Jw.

Berkelman, P.; Dzadovsky, M. (2010). Using Magnetic Levitation for Haptic Interaction. *Advances in Haptics*, pp.31–46. [Online] Available at: http://goo.gl/GjHFaa.

Bianchi, M.; Gwilliam, J.C.; Degirmenci, A.; Okamura, A.M. (2011). Characterization of an Air-Jet Haptic Lump Display. *Proceedings IEEE Engineering in Medicine and Biology Society*, (Query date: 2015-07-24). [Online] Available at: http://goo.gl/nMQjWG.

Bianchi, M.; Serio, A.; (2015). Design and characterization of a fabric-based softness display. *IEEE Transactions on Haptics*, 8(2), pp. 152–163.

Bianchi, M.; Valenza, G.; Serio, A., Lanatà, A.; Greco, A.; Nardelli, M.; Scilingo, E.P.; Bicchi, A. (2014). Design and preliminary affective characterization of a novel fabric-based tactile display. *IEEE Haptics Symposium, HAPTICS*, pp. 591–596.

Bilgincan, T.; Gezgin, E.; Mehmet, İ.; Dede, C. (2010). Integration of the Hybrid-Structure Haptic Interface : HIPHAD v1 . 0. *Proceedings of the International Symposium of Mechanism and Machine Theory*, p. 18.

Bolzmacher, C.; Hafez, M.; Khoudja, M.B.; Bernardoni, P.; Dubowsky, S. (2004). Polymer-based actuators for virtual reality devices. *Smart Structures and Materials: Electroactive Polymer Actuators and Devices (EAPAD)*, 5385, pp. 281–289. [Online] Available at: http://goo.gl/jv7J7P.

Bouri, M.; Baur, C.; Clavel, R.; Zedka, M.; Newman, C.J. (2013). "Handreha": A new Hand and Wrist Haptic Device for Hemiplegic Children. *ACHI 2013 : The Sixth International Conference on Advances in Computer-Human Interactions "Handreha":*, pp. 286–292.

Butterfly-haptics (2015). Maglev 200™ System. [Online] Available at: http://butterflyhaptics.com/products/system/ [Consulted November 1, 2015].

Carter, J.; Fourney, D. (2005). Research Based Tactile and Haptic Interaction Guidelines. *Guidelines On Tactile and Haptic Interactions Conference (GOTHI-05)*, pp. 84–92. [Online] Available at: http://userlab.usask.ca/GOTHI/research.pdf.

Chen, L.J.; Holbein, M.; Zelek, J.S. (2006). Intro to haptic communications for high school students. *Proceedings - IEEE International Conference on Robotics and Automation*, 2006(May), pp. 733–738.

Chinello, F.; Malvezzi, M.; Pacchierotti, C.; Prattichizzo, D. (2015). Design and development of a 3RRS wearable fingertip cutaneous device. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM*, 2015–Augus, pp. 293–298.

Chouvardas, V.G.; Miliou, A.N.; Hatalis, M.K. (2008). Tactile displays: Overview and recent advances. *Displays*, 29(3), pp. 185–194.

Coles, T.R. (2011). *Investigating Augmented Reality Visio-Haptic Techniques for Medical Training (PhD)*. Prifysgol Bangor University. [Online] Available at: http://goo.gl/g9hYjY. [Consulted November 10, 2015].

Coles, T.R.; Meglan, D.; John, N.W. (2011). The role of haptics in medical training simulators: A survey of the state of the art. *IEEE Transactions on Haptics*, 4(1), pp. 51–66.

Cortés, H.H.; México, C.; García, M.A. (2010). Aplicaciones para Entornos Educativos. *SISTEMAS, CIBERNÉTICA E INFORMÁTICA*, 7, pp. 46–49. [Online] Available at: https://goo.gl/koKxul.

CybergloveSystems (2015a). Cybergrasp. [Online] Available at: http://www.cyberglovesystems.com/cybergrasp/ [Consulted November 1, 2015].

CybergloveSystems (2015b). Cybertouch. [Online] Available at: http://www.cyberglovesystems.com/cybertouch/ [Consulted November 1, 2015].

DLR (2015). DLR light-weight robot III. [Online] Available at: http://www.dlr.de/rmc/rm/desktopdefault.

aspx/tabid-3803/6175_read-8963/ [Consulted November 1, 2015].

Do, P.; Homa, D.; Ferguson, R.; Crawford, T. (2012). Haptic Concepts. In A. El Saddik, ed. *Haptics Rendering and Applications*. Arizona: InTech, pp. 3–24. [Online] Available at: http://goo.gl/TfVMPY.

ElSaddik, A.; Orozco, M.; Eid, M.; Cha, J. (2011). Haptics: General Principles. In *Haptics Technologies*. Springer, pp. 1–21. [Online] Available at: http://goo.gl/Ytv9He.

Evreinova, T. V.; Evreinov, G.; Raisamo, R. (2014). From Kinesthetic Sense to New Interaction Concepts: Feasibility and Constraints. *International Journal of Advanced Computer Technology*, 3(4), pp. 1–33. [Online] Available at: http://goo.gl/QhjZG2.

Ferre, M.; Oyarzábal, M.; Campos, A.; Monroy, M. (2008). Multifinger Haptic Interfaces for Collaborative Enviroments. In I. Pavlidis, ed. *Human-Computer Interaction*. InTech, p. 522. [Online] Available at: http://goo.gl/WFXVCT.

Fogtmann, M.H.; Fritsch, J.; Kortbek, K.J. (2008). Kinesthetic Interaction - Revealing the Bodily Potential in Interaction Design. *Proceedings of the 20th Australasian Conference on ComputerHuman Interaction Designing for Habitus and Habitat*, pp. 89–96. [Online] Available at: http://goo.gl/xaTGh2.

Fontana, M.; Ruffaldi, E.; Salasedo, F.; Bergamasco, M. (2012). On the Integration of Tactile and Force Feedback. In A. El Saddik & ISBN, eds. *Haptics Rendering and Applications*. InTech, pp. 47–75. [Online] Available at: http://goo.gl/Txh3tz.

Forcedimension (2015a). delta.6. [Online] Available at: http://www.forcedimension.com/products/delta-6/overview [Consulted November 1, 2015].

Forcedimension (2015b). omega.7. [Online] Available at: http://www.forcedimension.com/products/omega-7/overview [Consulted November 1, 2015].

Frisoli, A.; Solazzi, M.; Reiner, M.; Bergamasco, M. (2011). The contribution of cutaneous and kinesthetic sensory modalities in haptic perception of orientation. *Brain Research Bulletin*, 85(5), pp. 260–266. [Online] Available at: http://dx.doi.org/10.1016/j.brainresbull.2010.11.011.

García-Hernández, N.; Bertolotto, F.; Cannella, F.; Tsagarakis, N.G.; Caldwell, D.G. (2014). How tactor size and density of normal indentation tactile displays affects grating discrimination tasks. *IEEE Transactions on Haptics*, 7(3), pp. 356–366.

Genoy Muñoz, J.W.; Rodríguez Ortiz, L.F.; Salinas, S.A. (2011). Interfaz háptica de cuatro grados de libertad para aplicaciones quirúrgicas. *Revista Ingeniería Biomédica*, 5(9), pp. 35–42.

Geomagic (2015). Geomagic® Haptic Devices. [Online] Available at: http://www.geomagic.com/en/products-landing-pages/haptic [Consulted November 1, 2015].

Golledge, R.G.; Rice, M.T.; Jacobson, R.D. (2006). Multimodal interfaces for representing and accessing geospatial information. *Frontiers of Geographic Information Technology*, p. 38.

González, L. (2011). Visión global sobre tecnología háptica. *Revista ACTA*, 61, pp. 115–122. [Online] Available at: http://goo.gl/AkxWtd.

Hapi (2015). HAPIfork. [Online] Available at: https://www.hapi.com/product/hapifork [Consulted November 1, 2015].

Haption (2015). VIRTUOSE TM 6D Desktop. [Online] Available at: http://www.haption.com/site/index.php/en/products-menu-en [Consulted November 1, 2015].

Hernantes, J.; Díaz, I.; Borro, D.; Gil, J. (2012). Effective Haptic Rendering Method for Complex Interactions. In A. El Saddik, ed. *Haptics Rendering and Applications*. InTech, p. 246. [Online] Available at: http://goo.gl/LNCJ8W.

Hoshi, T.; Takahashi, M.; Iwamoto, T.; Shinoda, H. (2010). Noncontact tactile display based on radiation pressure of airborne ultrasound. *IEEE Transactions on Haptics*, 3(3), pp. 155–165.

Iwamoto, T.; Shinoda, H. (2005). Ultrasound Tactile Display for Stress Field Reproduction -Examination of Non-Vibratory Tactile Apparent Movement-. *Proceedings of World Haptics 2005*, (Ultrasound Tactile Display), pp. 220–228.

Kajimoto, H.; Kawakami, N.; Maeda, T.; Tachi, S. (2004). Electro-tactile display with tactile primary color approach. *Proceedings of International Conference on Intelligent Robots and Systems*, 10.

Kamuro, S.; Minamizawa, K.; Tachi, S. (2011). An ungrounded pen-shaped kinesthetic display: Device construction and applications. *2011 IEEE World Haptics Conference, WHC 2011*, pp.557–562.

Kontarinis, D.A.; Son, J.S.; Peine, W.; Howe, R.D. (1995). A tactile shape and sensing display system for teleoperated manipulation. *IEEE International Conference on Robotics and Automation*, pp. 641–646. [Online] Available at: https://goo.gl/fdVxUA.

Kyung, K.; Kwon, D. (2008). Tactile Displays with Parallel Mechanism. In J.-H. Ryu, ed. *Parallel Manipulators, New Developments*. InTech, p. 498. [Online] Available at: http://goo.gl/3aRSzD.

Lee, J.S.; Lucyszyn, S. (2005). A micromachined refreshable Braille cell. *Journal of Microelectromechanical Systems*, 14(4), pp. 673–682.

Lévesque, V.; Petit, G.; Dufresne, A.; Hayward, V. (2012). Adaptive level of detail in dynamic, refreshable tactile graphics. *Haptics Symposium 2012, HAPTICS 2012 - Proceedings*, pp. 1–5.

Lim, T.; Germánico, G.B.; Medellín Castillo, H.I. (2014). Are you haptic a bad day. *Proceedings of the ASME 2014 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2014*, pp. 1–9.

López, J.; Galiana, I.; Torres, J.L.; Ferre, M.; Giménez, A. (2011). Análisis y diseño mecánico de una interfaz háptica para tareas de manipulación. In *CIBIM 10*. Oporto, Portugal, pp. 1633–1640.

Lumobodytech (2015). Lumo Lift. [Online] Available at: http://www.lumobodytech.com/product-category/lumo-lift/ [Consulted November 1, 2015].

Matysek, M.; Lotz, P.; Winterstein, T.; Schlaak, H.F. (2009). Dielectric Elastomer Actuators for Tactile Displays. *Third Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems Salt*, pp. 290–295.

MerkelHapticSystems (2011). MI Mannequin Trainer. [Online] Available at: http://www.merkelhaptics.com [Consulted November 1, 2015].

Mimics (2015). Haptic Master. [Online] Available at: http://www.mimics.ethz.ch/index.php [Consulted November 1, 2015].

Minamizawa, K.; Prattichizzo, D.; Tachi, S. (2010). Simplified design of haptic display by extending one-point kinesthetic feedback to multipoint tactile feedback. *2010 IEEE Haptics Symposium, HAPTICS 2010*, pp. 257–260.

MPB (2014). 7 DOF Haptic Interface. [Online] Available at: http://www.mpb-technologies.ca/mpbt/mpbt_web_2009/_en/7dof/specs.html [Consulted November 1, 2015].

Murayama, J.; Bougrila, L.; Luo, Y. (2004). SPIDAR G&G: A two-handed haptic interface for bimanual VR interaction. *proceedings of Eurohaptics*, pp. 138–146. [Online] Available at: http://goo.gl/s8OJ0g.

Nájera, E.; Díaz, A. (2005). Interacción pseudoháptica en el simulador de entrenamiento APSiDeTH. *Simposio Interacción 2005*, pp. 97–100. [Online] Available at: aipo.es/articulos/5/1374.pdf.

Nakamura, M.; Engineering, B.S.M.; Jones, L.A.; Supervisor, T.; Sonin, A.A. (2003). *A Torso Haptic Display based on Shape Memory Alloy Actuators. Thesis. Master of Science in Mechanical Engineering.* Massachusetts Institute of Technology.

Naud, M.; Chamaret, D.; Hamon, L.; Ullah, S.; Richard, E.; Richard, P. (2009). Human-Scale Haptic Interaction Using the SPIDAR. *VRC09 – Joint Virtual Reality Conference of EGVE – ICAT –EuroVR (JVRC 2009)*, 1, pp. 123–128. [Online] Available at: https://goo.gl/I0VpyZ.

Novint (2012). Novint Falcon. [Online] Available at: http://www.novint.com/index.php/novintfalcon [Consulted November 1, 2015].

O'Malley, M.; Gupta, A. (2008). Haptic Interfaces. In P. Kortum, ed. *HCI Beyond the GUI: Design for Haptic, Design for Haptic, Speech, Olfatory and other Nontraditional Interfaces*. MK, pp. 25–73.

Pacchierotti, C.; Tirmizi, A.; Bianchini, G.; Prattichizzo, D. (2013). Improving transparency in passive teleoperation by combining cutaneous and kinesthetic force feedback. *IEEE International Conference on Intelligent Robots and Systems*, p.6.

Pamungkas, D.; Ward, K. (2015). Tactile sensing system using electro-tactile feedback. *ICARA 2015 - Proceedings of the 2015 6th International Conference on Automation, Robotics and Applications*, p.8.

Pasquero, J. (2006). Survey on communication through touch. *Center for Intelligent Machines-McGill University, Tech. Rep. TR-CIM*, pp. 1–27. [Online] Available at: http://goo.gl/OciBuq.

Pasquero, J.; Hayward, V. (2003). STReSS: A Practical Tactile Display System with One Millimeter Spatial Resolution and 700 Hz Refresh Rate. *Proc Eurohaptics*, pp. 94–110. [Online] Available at: http://goo.gl/hYPgz9.

Pei, Q.; Yu, Z.; Niu; Xiaofan Brochu, P. (2009). Electroactive polymers for rigid-to-rigid actuation and Braille e-books. *Proceedings of SPIE - The International Society for Optical Engineering*, pp. 1–6. [Online] Available at: http://goo.gl/YaBluM.

Perez, A.G.; Lobo, D.; Chinello, F.; Cirio, G.; Malvezzi, M. (2015). Soft Finger Tactile Rendering for Wearable Haptics. *IEEE World Haptics Conference*, pp. 327–332.

Poupyrev, I.; Maruyama, S.; Rekimoto, J. (2002). Ambient touch: designing tactile interfaces for handheld devices. *Proceedings of the 15th annual ACM symposium on User interface software and technology*, pp. 51–60. [Online] Available at: http://goo.gl/dO7UCD.

Prattichizzo, D.; Pacchierotti, C.; Cenci, S.; Minamizawa, K.; Rosati, G. (2010). Using a fingertip tactile device to substitute kinesthetic feedback in haptic interaction. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, pp. 125–130.

Pyo, D.; Yang, T.-H.; Ryu, S.; Kwon, D.-S. (2015). Novel linear impact-resonant actuator for mobile applications. *Sensors and Actuators A: Physical*, 233, pp. 460–471.

Quanser (2016a). Omni Bundle. [Online] Available at: http://www.quanser.com/products/omni_bundle [Consulted January 15, 2016].

Quanser (2016b). Planar Pantograph Blocks. [Online] Available at: http://www.quanser.com/Products/2dof_serial_flexible_joint [Consulted January 15, 2016].

Rantala, J.; Raisamo; Lylykangas, J.; Ahmaniemi; Makela; Salminen; Surakka (2011). The role of gesture types and spatial feedback in haptic communication. *Tansactions on Haptics*, 4(4), pp. 295–306. [Online] Available at: http://goo.gl/e8p07A.

Richter, H.; Blaha, B.; Wiethoff, A. (2011). Tactile feedback without a big fuss: simple actuators for high-resolution phantom sensations. *Proceedings of the 13th International Conference on Ubiquitous Computing - UbiComp '11*, pp. 85–88. [Online] Available at: http://goo.gl/tzaYpm.

Richter, H.; Manke, F.; Seror, M. (2013). LiquiTouch: Liquid As a Medium for Versatile Tactile Feedback on Touch Surfaces. *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*, pp. 315–318. [Online] Available at: http://goo.gl/0rChkZ.

Robothand (2015). Haptic robot HIRO III. [Online] Available at: http://robothand.eu/en/products/robotic_hands/haptic_robot_hiro_iii/ [Consulted November 1, 2015].

Runyan, N.; Blazie, D. (2010). EAP actuators aid the quest for the "Holy Braille" of tactile displays. *Spie*, p.12. [Online] Available at: http://goo.gl/Q3JvkM.

Russomanno, A.; Gillespie, R.B.; O'Modhrain, S.; Burns, M. (2015). The design of pressure-controlled valves for a refreshable tactile display. *IEEE World Haptics Conference, WHC 2015*, pp. 177–182.

Sabater, J.M. (2003). *Desarrollo de una interfaz paralela y en experimentación en control de sistemas hápticos y teleoperados (Ingeniero de Sistemas)*. Escuela Politécnica Superior de Elche.

Sarakoglou, I.; García-Hernández, N.; Tsagarakis, N.G.; Caldwell, D.G. (2012). A high performance tactile feedback display and its integration in teleoperation. *IEEE Transactions on Haptics*, 5(3), pp. 252–263.

Sato, K.; Tachi, S. (2010). Design of electrotactile stimulation to represent distribution of force vectors. *2010 IEEE Haptics Symposium, HAPTICS 2010*, pp. 121–128.

Sato, M. (2002). Development of string-based force display: SPIDAR. *In Proc. The Eighth International Conference on Virtual Systems and Multi Media VSMM*, pp.1034–1039. [Online] Available at: http://goo.gl/XAJ5bh.

Sensable (2016). PHANTOM OMNI® Haptic Device. [Online] Available at: http://www.dentsable.com/haptic-phantom-omni.htm [Consulted January 15, 2016].

Senseg (2015). Senseg Tixel. [Online] Available at: http://www.senseg.com [Consulted November 1, 2015].

Simeonov, S.; Simeonova, N. (2014). Graphical Interface for Visually Impaired People Based on Bi-stable Solenoids. *arXiv preprint arXiv:1401.5289*. [Online] Available at: http://goo.gl/Jlu3GT.

Sledd, A.; O'Malley, M.K. (2006). Performance Enhancement of a Haptic Arm Exoskeleton. *2006 14th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pp. 375–381.

Song, A.; Liu, J.; Wu, J. (2003). Softness Haptic Display Device for Human- Computer Interaction. In I. Pavlidis, ed. *Human-Computer Interaction*. InTech, pp. 257–279. [Online] Available at: http://goo.gl/jDtlA5.

TacticalHaptics (2013). Reactive Grip™ Motion Controller. [Online] Available at: http://tacticalhaptics.com/products/ [Consulted November 1, 2015].

TactusTechnology (2015). TACTUS Tactile Layer. [Online] Available at: http://tactustechnology.com/technology/ [Consulted November 1, 2015].

Thrustmaster (2015). Thrustmaster TX Racing Wheel Ferrari 458. [Online] Available at: http://goo.gl/HR3Uoj [CConsulted November 1, 2015].

Torres, D. (2012). *Diseño de ortoprótesis para mano*. Mexico DF: Universidad Nacional Autónoma de México. [Online] Available at: http://goo.gl/3T57Xe.

Ueberle, M. (2006). *Design, Control, and Evaluation of a Family of Kinesthetic Haptic Interfaces (Doctor - Engineer)*. Technical University of Munich.

Unige; Unexe; Percro; Uhan; Swl (2008). *Whole Haptic Interface Hardware. Report.*, [Online] Available at: http://goo.gl/Kn4VdC.

Vélez, A. (2011). *Diseño mecánico de un interfaz háptico para realidad virtual. (Ingeniero Mecánico)*. Universidad Carlos III de Madrid.

Wagner, C.; Lederman, S.J.; Howe, R.D. (2004). Design and performance of a tactile shape display. *Haptics-e*, p.6.

Wagner, S.R. (2014). *Haptic and Exoskeleton Devices for Neurorehabilitation of Upper Limb Paralysis : a State of Art and a Night Landing Task*. Northern Michigan University. [Online] Available at: http://goo.gl/75PUOU.

Wang, F. (2014). *Haptic Energy Consumption. Application. Report.*, Dallas, Texas. [Online] Available at: http://goo.gl/78bICu.

Worldhaptics (2012). Haptics Technical Commite, Companies. [Online] Available at: http://www.worldhaptics.org/companies [Consulted November 15, 2015].

Xu, C.; Israr, A.; Poupyrev, I.; Bau, O.; Harrison, C. (2011). Tactile display for the visually impaired using TeslaTouch. *Proc. CHI EA '11*, pp. 317–322. [Online] Available at: http://goo.gl/cDLu5c.

Yang, Y. (2013). *Design and Control of an Integrated Haptic Interface for Touch Screen Applications (Doctorat)*. Université Lille 1 [Consulted November 9, 2015]. [Online] Available at: http://goo.gl/9J8s4R.

Yazdian, S.; Doxon, A.J.; Johnson, D.E.; Tan, H.Z.; Provancher, W.R. (2013). 2-DOF contact location display for manipulating virtual objects. In *2013 World Haptics Conference, WHC 2013*. Daejeon, Korea: IEEE, pp. 443–448.

Youngblut, C.; Johnson, R.E.; Nash, S.H.; Wienclaw, R.A.; Will, C.. (1996). Kinesthetic interfaces. In *Review of virtual environment interface technology*. Alexandria, Virginia: Institute for Defense Analyses, pp. 117–154. [Online] Available at: http://goo.gl/vL5B4B.

Zeng, T.; Giraud, F.; Lemaire-Semail, B.; Amberg, M. (2010). Analysis of a New Haptic Display Coupling Tactile and Kinesthetic Feedback to Render Texture and Shape. In A. M. L. Kappers, J. B. . van Erp, W. M. Bergmann Tiest, & F. C. T. van der Helm, eds. *International Conference, EuroHaptics*. Springer, pp. 87–93.

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