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CONCEPT AND APPLICATION OF VIRTUAL REALITY HAPTIC TECHNOLOGY: A REVIEW

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ABSTRACT

Haptics has been a major part of both future virtual reality experiences and everyday consumer electronics. Wearable technology, since it is in contact with human skins, will be the most likely place to deploy these solutions. Haptics platform is a fast-evolving area and the virtual reality technologies has matured and is giving suitable assistance to robotic surgery and people who are handicapped. This paper reviews the general concept of virtual reality haptics, altogether with its applications, previous research findings, the challenge and its superiority for developing a virtual reality prototype/devices and integration of virtual reality concept with the bilateral control system platform. And lastly, potential upcoming works were discussed and suggestions will be put together for melioration of review findings.

Keywords: *Virtual Reality, Sensory, Tactile, Haptics, Manipulation, Force Feedback*

1. INTRODUCTION

The word haptics originates from the Greek verb “haptesthai” which relates to the ability to touch and manipulate objects [1]. Subsequently the early part of twentieth century, haptics term has become common for the studies of active touch on real objects by humans [2]. While active touch is referred to as bidirectional flow of energy and information between the real, virtual environment and the human sensory modality. The interaction of objects or environment could be made by humans, machines or combination of both and; the object and environments can be real, virtual, or combination of both too. With the technological advances, haptics feedback has been employed to transmute into some specialized tasks by providing an auxiliary sensory channel in addition to its mainstream applications [3]. The interaction may be augmented by other sensory modalities such as vision and audio. The impact from this merge of sensory input and haptics have carried many different disciplines including biomechanics, psychology, neurophysiology, engineering, computer science, medical, agriculture and even aeronautics to review and analyse human touch and force feedback with the external environment. There are also some recent advances in haptics research that develop a system of contactless haptics feedback in 3D space as stated in [4],[5]. Notwithstanding that technological and algorithm challenges, it appears to be inevitable to develop heaps of haptical active devices for benefits of mankind. So far, the research efforts on particularised tasks in haptics have been dominated by surgical robotics and rehabilitation simulation [6],[7]. Usually, the device enables the interface with virtual or physically vicinity. The action tasks are typically performed by hand in the real daily chores, such as manipulating objects and exploring their properties [8].

Haptics discipline are undeniably great, necessitates expertise in some sub-knowledges of engineering fields. In these days, haptics technology is classified within 3 basic types namely as Human Haptics, Machine Haptics and Virtual Augmented Reality Haptics. Human haptics is concerned about the study of human sensory perception and contact manipulation perceived by the senses from external force [9]. Machine haptics as shown in Figure 1 are made up of a design, construction and use of machines to replace or augment human touch and other forms of stimuli where the generic force will be measured by sensors through actuators to sense force, dimensions or temperature [10]. The next one will be virtual reality haptics. Basically, Virtual Reality is 3D image or a setting produced by computer that can act reciprocally by using special equipment in seemingly real or physical way. Virtual reality is closely related with computer haptics whereby the algorithms and software are associated with the aid of computer graphics or vision aid; for instance, images or videos taken by the embedded cameras to document renderings of generated touch in virtual objects [11].

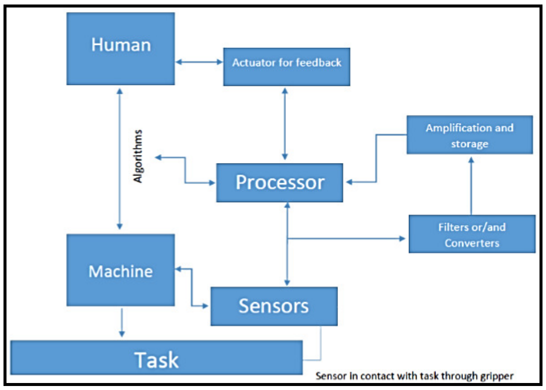

Figure 1: Block Diagram of Machine Haptics [10]

Figure 2 shows the common interaction between human and machine in general haptics system whereby forces and motion area being produced though on different forms of energy through effector, sensors and motor.

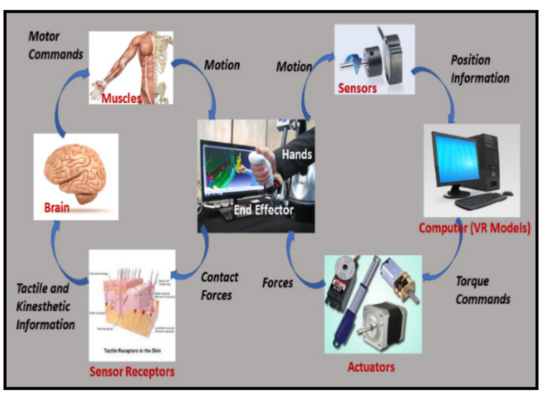

Figure 2: Human-Machine Interaction of Haptics

Briefly, this paper is written to present insight about the terms and upper hand of virtual reality only and its relations with the haptic technology. From the existing studies, this research field gave potential to expand and advance in various sphere especially in education, training and clinical therapies to aid people by distracting mind and flooding sensories with a positive experience and safe environment. This reduces the need for physical modifications to machinery and saves material, time as well as financial outlay to get series of treatment or learning. In this paper, the structures are as follows. In Section II, a further elucidation is given on virtual reality haptics concepts and brief introduction on how the system works. Current experiment, research works and example of commercialized virtual reality haptics devices or robots will be introduced in Section III. Following that, Section IV will discuss about the integration between bilateral control system of haptic that consists of master and slave system with the augmented virtual reality of the system. While in Section V, the benefits of virtual reality into the haptics technology and future humankind will be described. For Section VI, discussion about the review will be stated. Finally, conclusions and recommendations for forthcoming works are drawn in Section VI. Research and work contained within this paper are only about the application and research reviews of virtual reality and haptics technology. This does not include the knowledge about concern and challenges of virtual reality, haptic communication, haptic perception or haptic poetry.

2. VIRTUAL REALITY CONCEPTS

Haptic technology has shown blended possibilities of art and science for creating software algorithm that synthesize computer-generated forces and tactile stimulation to be exhibited to user for the perception and manipulation of virtual objects via touch as shown in Figure 3. Virtual environments (VE) or commonly popular as virtual reality is a computer-generated synthetic environment which can interact with a human user to perform perceptual and motor tasks such as squeezing an orange, grasping a bottle and cutting a roll. In particular, a person moving his hand in virtual environment for gripping or touching an object as if the environment is real.

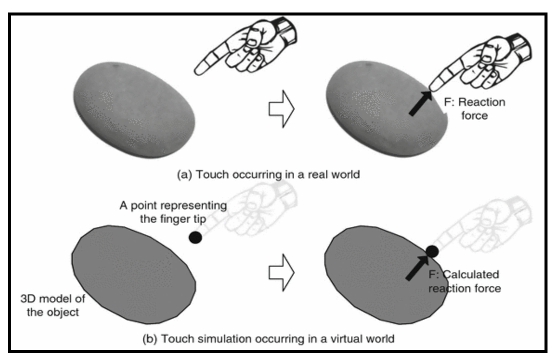

Figure 3: Concept of touch in real and virtual world [11]

As soon as users' fingertip interacts with that object, it exerts a rejoinder force against the finger to avert it from penetrating the object. Along with this, users will sense influence along with the object's texture, passing through muscle and mechanoreceptors. The dexterous receptors manipulate specific object in environments, with aid for seeing or/and hearing them, offers a compelling event and leaving users immersed in the designed atmosphere with awesome satisfaction. It is likely that amazing experience in VE can be achieved by a simple haptic interface with embedded visual and auditory display to create incredible sensation to the users although by true full touch simulation. Researchers in [2] and [12] has discussed that, a real object can be created in a virtual world by generated model in computer, creating from function library and algorithm database in specialized software. Commonly, user's fingertip or hand gestures can be represented as a point called an 'avatar'. A typical VE consists of a computer display or a layout that can project computer- generated synthetics environments or visual images to the outlook direction and a special glove or mini device whereby the users can command the computer to reciprocate and do corresponding works as shown in Figure 4 and Figure 5.

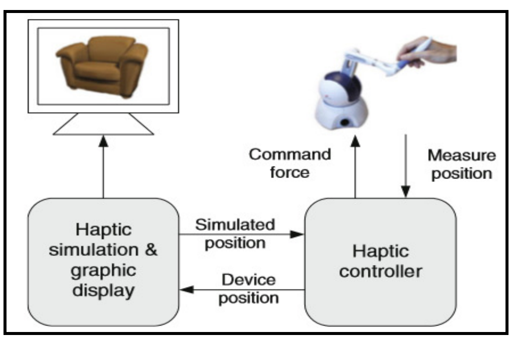

Figure 4: Force representation in a virtual world [12]

In scientific understanding, the basic principle to make objects in the virtual environment stipulate information on the geometry, texture, slippage and ambient temperature of item's surface. Being able to trace, experience and touchable is much simple. When initial sense of contact from a person's hand interacts with an object, the nerve receptors in the skin stimulates and excite. Whereby, the receptors provide tactile information of touched objects to the brain. When the hand applies force, kinesthetic information (force feedback) comes into play by providing physical information about the position and motion of the hand relative to the object. By applying this science concept into virtual reality haptics, after human user controls the generic probe (best known as end-effector) of the haptic device, position sensors of the tools will relay its end position to the computer. In every interval period, computer that controls the end-effector will check for friction or clash between the simulated stylus and the virtual objects positioned in virtual environment.

Furthermore, the haptic rendering system calculates the reaction forces/torques that must be counted on at the human-device interaction point as shown in experiment example in Figure 6. It will control the actuator (usually an electric motor) attached on the device to a tactual perception of the virtual objects. Let's say that no touch or collision was detected, no forces will be computed. Moreover, users feel free to move the stylus, wandering through empty surface. In simple words, an enormity of a reaction forces is assumed proportional to the indentation deepness and forces are applied immediately following surface penetration. The concept of virtual reality haptics and general idea has been discussed in this section. In the next section, current experiment and research works as well as some of commercialized virtual reality haptics devices or robots will be reviewed for more further.

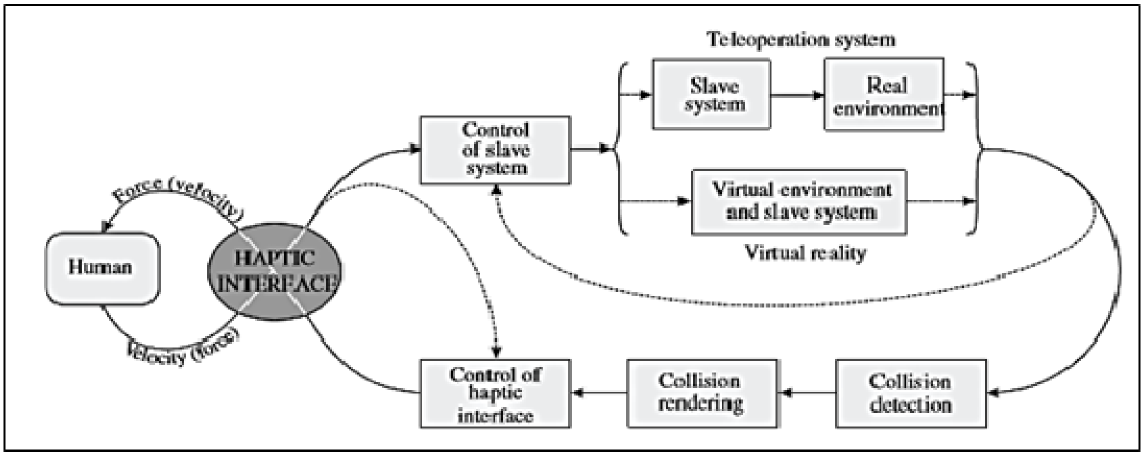

Figure 5: Haptic system; interaction between a human and the haptic interface represents a bidirectional exchange of information [8]

Figure 6: Example of Virtual Reality Haptics Experiment

3. AVAILABLE RESEARCH WORKS

3.1 Current Experiment and Research Works

In this section, findings from previous existing works will be studied and divided into different type of research fields. Kind of research works are based on clinical training which involve rehabilitation exercises and physiotherapy, medical robotic surgery, virtual simulator for endodontics treatment, pilot simulator, military training, teleoperation and telerobotic, haptics driver support systems and also virtual manufacturing and assembly.

Simulation of real-world tasks in the employment of integrated virtual reality (VR) haptical devices gave significantly attributes in research works. There are numerous research fields studying about this technology. One of it is associated with neural activity that give potential for clinical stroke applications and rehabilitations for patients diagnosed with stroke or experienced accidents as reviewed in [13-18]. In VR based rehabilitation, bimanual exercises can be brought out by making use of haptic rendering techniques which permit object manipulation by using two haptic devices. For instance, a low-cost haptic aided glove equipped with sensors on the wrist allowing the identification of wrist orientation, by using VR which means that patients are able to make essential motions during the training and are guided to reach different goals of increasing complexity until the completion of rehabilitation [13] while [14] developed the experiments by adding the measurement of associated neural activity by functional magnetic resonance imaging (fMRI) to receive the force feedback in form of brain sensory feedback. To make it more interactive, real-time interaction and to enhancing the rehabilitation session, [15] also has introduced the development of haptic-enabled whack-a-mole games in arcade games. The system introduces a collision handling method to compute feedback force and provide realistic and adequate data through the haptic device in specific exercise.

Besides that, [16] also has proposed that, system could provide enhanced visual feedback about movement trajectory and collects electromyography (EMG) from patient to perform hand motion recognition, which is beneficial to improve motor function task learning and recognize the action of grasp as well as evaluate the patients' recovery. This applied concept and work also gave contribution for lower limb (foot-based) interaction with virtual environments as proposed in [17], with VR assistive technology enhancing the sense judgement and alleviate boredom. Generally, haptic interaction entails spherical end-effectors, such as robots, with invariant shapes. Furthermore, the position of the end-effectors can be traceable haptically after object contact, which impacts the ability to determine the real position of the end effector and dynamically manipulate the object [18]. Thus, with VR technology build on the system, patients and physiologist are able to determine the position of limb and follow the pattern while collecting generated data output for diagnosis and monitoring patient capabilities during physiotherapy.

In parallel to the VR in medical training stations and surgery, the use of VR-robotic technology to aid surgeons and physicians has been actively studied [19-26]. In fact, VR haptic in medical applications are subdivided into human/tool and tool/tissue interfaces. In some advocate observation as reviewed by [19], method for laparoscopic surgical, a minimally invasive surgery (MIS), can be conducted in the operating room, while others promote animal and simulated models or a combination of surgery-related tasks. Minimally invasive surgery is a complex task that requires a synthesis between VR simulations and haptic information. Thus, they introduced a skill scale using Markov Models (MM) to create new quantitative knowledges of the forces and torque applied by surgeons on their instruments during the surgery while developing a modified surgical grasper containing embedded sensors capable of measuring forces and torques being applied during surgery operation. In [20], functional prototype and impedance control of a six degrees of freedom haptic interface has been designed to train surgeons for laparoscopic procedures, through virtual reality simulations. The device features a low apparent inertia with high structural stiffness, cause of parallel kinematics with grounded actuators. Not just that, [21],[22] also proposed the realistic simulation of tool-tissue interactions. [21] has demonstrated deformation and cutting of the oesophagus, where the user can haptically interact with the virtual soft tissues and see the corresponding organ deformation on the visual display simultaneously for training purpose. But then, [22] was dedicated for endoscopic training where endoscope is allowed to react to contact forces along six degrees of freedom, as in [20]. The model takes into account end point position and appropriate contact forces. The illusion of physical movement inside the environment is obtained by computing control inputs based on impedance environment.

Other studies focused in human/tool interaction are stated in [23-26]. [23-25] is a virtual reality simulator for training endodontics operations. But, simulator in [23] consists of a custom 4DOF haptic device for tracking and force feedback. During the simulation, the movements user does with the manual files are tracked and at the end displayed the forces applied during the procedures, the direction and the amplitude of the movements and the final result of the tooth preparation. A haptic device called as iFeel3 was designed, where it can output force in 3D space and can record real-time six-dimensional motion of the handle as well as increased the stiffness of its previous prototype [24].

In another work, a 3D Virtual Drilling Simulator of the edentulous space of the dental arch in oral rehabilitation, controlled by the Novint Falcon haptic device was designed and recognized the relevance of the simulator as a support tool for training students in Implant Dentistry [25]. Silvio *et. al* proposed the Sensimmer platform [26] which represents research on simultaneous haptics and graphics rendering of 3D models which obtained from medical imaging data, such as Magnetic Resonance Imaging (MRI) or Computed Tomography (CT). In this work, image segmentation techniques are used to determine the anatomies of interest from the images.

In order to achieve satisfactory fidelity and meets the needs of end users, a degree which the simulated tasks reproduce, foster knowledge, skills and behaviours reliably capable are transferred to real-world training applications. It delivers affordable and accessible training systems of virtual simulation technologies in military training and civilian surgical contexts [27].

Furthermore, there are also research work that contribute in nuclear operation field. As reviewed in [28], a 3D digital mock-up simulator system is built to simulate the nuclear facilities. The human interface of a haptical virtual arm is proposed to improve the reality during the remote operation of the apparatus in virtual nuclear facilities. As generally known, remote operation in nuclear facilities is hazardous since human access is restricted due to the effects of high radiation. This application of haptic feedback system generally called as teleoperation system. Thus, using a haptic device in the roll of a master manipulator enhances the throughput and the reliability of the simulation because of the kinetic sense of reality. As example, Sansanayuth *et. al* in [29] implemented two Phantom Omni haptic devices connected in master-slave configuration for constructing the inverse dynamic controller in teleoperation system. They demonstrated the improved trajectory tracking performance of the system after the controller is configured.

Along with that, there is also an interface designed to give the operator a unique view to remotely navigate the autonomous teleoperated agent with minimal cognitive overload and minimal risk of accidental input, as stated in [30]. Nowadays, with a consistent and high speed for live streaming, researchers in [31-36] promote tele-robotic system which refers to controlling the robot system based on internet connection. These projects are a new field of engineering in current decades and requires an understandable knowledge of virtual reality and haptics for embedding with the system. This architecture is acknowledged to solve the delay time which is unpredictable during the communication in an uncertain environment. Therefore, the advantages for implementing the system is the operator is now able to employ and interact with the robot for task sequences and robotic actions smoothly. Together with haptic feedback, VR technology and less time delay from internet sources, objects will be easy to handle, not get out of control and gives on the spot reaction.

Besides that, Sebastian *et. al* stated in [37-39] that a large number of haptic driver support systems have been studied in previous years. Haptic driver support systems are all about haptic feedback control stick that aided drivers in a car-following task. This system retained the general idea about virtual reality haptics but developed it into driver systems used in cars. It is equipped with a warning system (using vibrations) and guidance system (using continuous forces), improving the performance of drivers. There are haptic systems that support the human in driving subtasks, such as lateral control, car-following, navigation, and eco-driving. Moreover, various channels through which the haptic systems can communicate with the driver, such as the steering wheel or seat. Some systems use binary warnings to inform the driver that he/she is too close to a lead car, whereas other systems suggest an appropriate action by applying a counter force to the gas pedal.

In view of the fact that haptic VR based were considerable feats for training medium in terms of safety and expenses, it could also support a measurement of competence; much akin to a pilot training in a flight simulator. For instance, the system provides a less stressful learning environment for the surgical student while eliminating risks to the patient in complex surgical procedures. There are also other simulators under development, coupling the VR computer graphics with haptic (reaction) feedback devices in order to provide a fully immersed virtual environment, combining both visual and haptic feedback.

In industry, companies demand advance technologies and competitive solutions for virtual reality approach to design equipment in shorter production runs and better responses [40],[41]. Research in [42] also concluded that building a model in virtual way is much more interactive than making it in conventional way as it helps users to understand better. Thus, the term of virtual manufacturing is established. Virtual manufacturing concepts originate from machining operations and are available in a lot of applications in different fields such as casting, forging, metalworking and robotics.

Virtual manufacturing idea is simply described as ‘manufacturing in the computer’ [43]. This definition contains two concepts which are the process itself (manufacturing) and environment (computer). Virtual reality (VR) is a new method of visual operating and interacting of complex data that can be realized by computers, in which one would have an immersed sense to observe and operate objects in three dimensions timely and unboundedly as work developed about robotic manufacturing cell in [44] and virtual vehicle manufacturing [45]. With a high degree of detail, different kinds of lights, textures and materials inserted to the scene reached a high degree of realism, at the expense of final performance during handling 3D objects. Generally, VR applications in manufacturing have been classified into three groups; design, manufacturing processes, and operation management [46].

VR is a new developing technique and a complex simulation tool for industry, it builds a simulated environment in which researchers can do many important functions such as product design, assembly, inspection, layout planning, training and performance parameters test in an unaffected way. These works also can be known as virtual assembly and virtual prototyping. By means, virtual prototypes are made to interact with objects in VE. The prototypes highlight all the relevant features of the product that has to be investigated, evaluated and improved [47]. For example, analysis of movements characteristics and elastic dynamics for man-machine interaction technology in post-press processing equipment which is die-cutting machine design and manufacture [48].

Beneficial to meet the requirements of market competition, VR technologies not only reduce effectively the time and cost, but also optimize complex products in the design process. To validate and provide users on how to work with 1:1 scale digital objects in real world, a virtual environment for a robotic cell is developed with layout design and implementation planning [49]. Virtual reality is a rapidly developing computer interface that strives to immerse the user completely within an experimental simulation, thereby enhancing the overall impact and providing a much more intuitive link between the computer and the human participants. For instance, these devices significantly enhance task performance and help designers and engineers to design and evaluate computer generated mock-ups prior to building any physical prototype or, deciding the most appropriate assembly sequence. Supposing to achieve a multi-modal interface, the second output modality chosen is haptic feedback. With the developments of Vega project, an infrastructure corresponds to one of the manufacturing field which is CAD/CAE [50], this research works proved that virtual reality can be flexible in manufacturing and assembly simulation. In this way, the capability of advanced manufacturing machines and resources can be fully exploited and utilised.

3.2 Commercialized Products of VR

In this section, developed and commercialize products of VR devices and robots parallel with haptics technology will be introduced. There are various kinds of robots and virtual-haptics devices that suits in different practices and applications such as for cinema and media entertainments, gaming, surgery, 3D object scene, and exoskeleton controller have been developed and have been anticipated gaining interest from societies or organizations.

Entertainment and gaming world are full of excitement, magical events, advance technologies and evoke pleasant response and generate human stimulation. Along with the rapid technology, human tend to feel the realness in virtual milieu although it is just an interaction between the interface of computer-generated surroundings. Example of marketable surgical robotic systems known as ZEUS by Computer Motion and the daVinci system by Intuitive Surgical, Inc. These kinds of robots are still in clinical trials and have limited haptic feedback, may be redefined before considerably guaranteed for operation theatre use in the future. Nevertheless, due to the robots' enhanced precision, range of motion, dexterity and 3D endoscopic visualization [51], driven feedback provides medically relevant information that could improve the performance of a surgical task in various ways.

In addition to the VR world, AxonVR [52], a software company based in Washington, created a haptic technology that enables most realistic touch sensations in the world for the first time. It's product which was commercialized as HaptX™ is a haptic textile that delivers lifelike touch, allowing users to feel the texture, shape, motion, vibration, and temperature of virtual objects. It's an enormous metal box with some buttons and blinking lights, and it occasionally makes ominous noises. HaptX™ is a thin, flexible haptic textile made up of an array of microfluidic actuators. By varying pressure and temperature at each actuator, HaptX creates sensations ranging from the brush of a butterfly's wings to the impact of a punch. From the warmth of a cup of coffee to the chill of a snowball. HaptX can bring the sense of touch to any surface.

Whereas, HaptX Skeleton is a lightweight exoskeleton that extends the realism by applying physical forces to user's body. Uniquely, the developer intends to allocate around U$ 5.8 million to build out HaptX platform which will be licensed directly to businesses such as theme parks and VR arcades. The company's HaptX Skeleton is a full-body exoskeleton that uses force feedback to enable both locomotion and macro-haptic feedback to entire limbs. HaptX Skeleton extends HaptX's immersive capabilities by delivering force feedback. HaptX Skeleton can be programmed to assist or resist motion.

Besides that, AxonVR also offers a HaptX SDK which allows developers to easily add haptic properties and effects to their content. The HaptX SDK includes a plug-in for leading game engines that lets content creators add realistic touch sensations to their projects without writing any code. HaptX SDK is a software toolkit that empowers developers to create touch-enabled experiences. HaptX SDK works seamlessly with leading game engines, making it easy for developers to create VR experiences that leverage advanced haptic capabilities.

Body motion tracking technologies are currently being developed for the future of virtual reality. Similar to hand tracking technology, body motion tracking is a concept in the field of haptics technology, where body movements are being interpreted by motion sensors as perceived input and turns it into useful controls. Basically, with this technology, the user himself is the controller. With recent advancements in haptics, body motion tracking has never been left out of the game, and has been a primary focus of third-party developers who envision a more realistic and immersive VR experience made possible with the integration of virtual reality and haptics. One of body motion tracking technologies are Control VR. The wearable controller assures to give a fully immersive virtual reality experience by essentially removing the secondary input mechanisms such as the traditional mouse-and-keyboard combo. Control VR is worn on the user's body, having multiple sensors built within its unit that work to sense physical movements from the user. The controller is able to make the user as the primary input device for computer games that make use of fast hand and arm movements, such as first-person shooter games and role-playing games.

On top of that, The Dexmo F2 developed by Dexta Robotics and HEXOTRAC [53] are also a VR hand exoskeleton device. Due to the detailed haptic feedback on Dexmo F2; a 5-digit hand exoskeleton, handlers are able to experience the sensation of lifting up objects in virtual content. Aside from its ability to give haptic response, it is capable to replace old-style remote control for radio-controlled toys and remote lighting fixtures. While, HEXOTRAC is a 3-digit hand exoskeleton which proposes a new approach for high resolution finger tracking and force feedback with a single attachment at the fingertip through 6DoF linkage that facilitates with a sensor system for tracking and permits bidirectional feedback force at the fingertips.

Along with it, a virtual reality glove named Gloveone by NeuroDigital Technologies, is able to provide haptic feedback through hands and fingers for user's felt. With supported VR headset, Gloveone offers user to sense and interact with any virtual object or environment based on the content projected from VR as the glove itself is implanted with numbers of haptic sensors. VR glove lets users to feel object's physical physiognomies as well as doing object manipulations including throwing and punching as if it was done in real-time. This glove also is much similar like The Hiro III, a robotic hand that transmits touch information to the fingertips of the user.

Initiative by Virtuix and mechanical and electronics engineering students in Rice University, gaming company focusing on VR, Hands Omni was made. The illusion of touching an object and creating the ability to distinguish various physical surface of an object by inflating and deflating tiny air bladders embedded into strategic parts of the glove. With a VR headset linked to this device, allows users to manipulate a virtual object as if it is done outside from virtual reality.

Aside from that, there is also a gaming vest called as KOR-FX that utilized acoustic feedback known as "acousto-haptics", where in turn processed into haptic feedback. It uses software to finely tune the feedback felt by the user. This vest is also beneficial for games and entertainment experiences wherever it is compatible as it can be linked with some PCs and gaming consoles including X-Box and HoloLens, making it an indispensable tool for haptics in virtual and augmented reality.

Developed by Novint Technologies Inc., a motion controller commercialized as Novint Falcon is a controller that gives haptic feedback to media experiences such as gaming purposes. This 3-DOF translational delta parallel robot can be regarded as the replacement of spherical joints by rotational joints [54]. This device also much more reasonably priced compared to its counterparts and drew attentions for researchers to do robotic control as discussed in [55], which simulates virtual iCub robot to perform tasks. The device also was also used for visual representation and identification purposes.

Meanwhile, haptic-enabled electromechanical device known as Phantom Omni by SensAble Technologies, is a haptic-enabled device specifically intended for manipulation of virtual objects and applied in various practical applications in aviation, teleoperation, forestry harvesting [56] and robotic industries. The device structure is a controller arm with 6 degrees of freedom movement sensing, and a stylus for object manipulation. Yet, this device has been used for kinematic model for precise motion control identified parameters [57], simulation of sensory mode interaction of different stiffness and friction [58] and coordinate transformation between kinematics model and Touch X device [59].

Differently for PrioVR, this haptics device is technology embedded with inertial sensors to accurately provide motion tracking with a 360-degree field of view. Unlike any haptics technology initiatives aforementioned, PrioVR is controller-free interface because it is meant to be placed on user's body. All inertial sensors are strategically placed within the full-body suit and data gathered by these sensors are then translated into interactions on screen in real time with low latent period.

On top of that, Sixense company are currently developing a wireless solution to hand input in virtual reality with the STEM System™. STEM System utilizing alternating current (AC) electromagnetic field [60] to precisely track body movements in terms of position and orientation within a radius of a stationary base. X-ray spectrometers combined with electron microscopes are powerful tool for material micro analysis. The advantage is that it is able to track up to five tracking points, creating an unrestricted level of movement freedom. A handheld wireless controller engaged to create movement data that is transferred onto the base station, turn interpretation into on-screen motion. The technology was demonstrated with demos on virtual shoe shopping and interactive lightsabres for gaming.

Sixense also developed MakeVR software [61],[62] which imitates blocks or Play-Doh in real life to combine objects together like LEGO or Minecraft blocks. MakeVR uses two Razer Hydra controllers, Sixense software, the ACIS CAD engine, THI (Two Handed Interface) Engine, a PC, and a display. This application verge on an accessible digital sandbox for making 3D objects scenes for beginners and with advanced tools for experts. It presents a pro CAD engine through a natural immersive two-handed interface.

There is also a VR accessory called Stompz to be worn on the user's shoes to provide real-time feedback and control to games. It is also wireless and give free movement for user's interactions with on-screen objects. A simple run or jump with Stompz can be read as motion, and is processed into input that makes anything on screen to respond based on the user's movement. Stompz capable to bring VR experiences to a new level of freedom in haptics technology.

Tesla Studios, Scotland-based VR haptics company, is currently developing a full-body haptics suit kind like PrioVR that is made to complement virtual reality experiences. The Tesla Suit is composed of a belt and modular units such as gloves, a vest, and trousers. The belt acts as the control centre of every haptic feedback felt by the user while, the modular units are filled with tiny electrical impulse units that give off signals felt as haptic feedback [63]. Tesla Suit, is a futuristic way to experience VR while simultaneously feeling every action is almost similar to, an Ironman suit. The suit was built with motion capture system technology specs. This incredible suit was also made to work with VR headsets, gaming consoles and smartphones as well as equipped with climate control system technology.

Strap™ and Vest™ by Woojer is also a device that employed particular frequencies signals when attached to the user's body, creating an impression of tactile feedback through acoustic signals. The technology works by receiving audio signals from the source, and interprets the acoustic signals to produce tactile feedback in the form of rumbles in any media content. Aside from that, a wearable exoskeleton named as CyberGrasp which uses tendons and actuators to apply resistance perpendicularly to individual fingertip of finger [64-65]. However, its usability is restricted since its limited control bandwidth and position sensor resolution not offering stable and realistic force feedback. And lastly, The Hiro III is a 5-fingered haptic interface robotic hand that transmits touch information to the fingertips of the user [66]. The aim of the development of HIRO III is to provide a high-precision three-directional force at the five human fingertips.

In the world of virtual reality, some realism is needed to further enhance the immersive experiences that it brings. With the help of these full body-tracking technologies that have been announced publicly as shown in Figure 7, the future of VR is bright, paired with virtual experiences are indistinguishable from real life. Simply, an adrenalin rush and immersive sensation delivers powerful and high impact experience when paired with VR headsets.

Figure 7: Virtual Reality Haptics Devices available in market

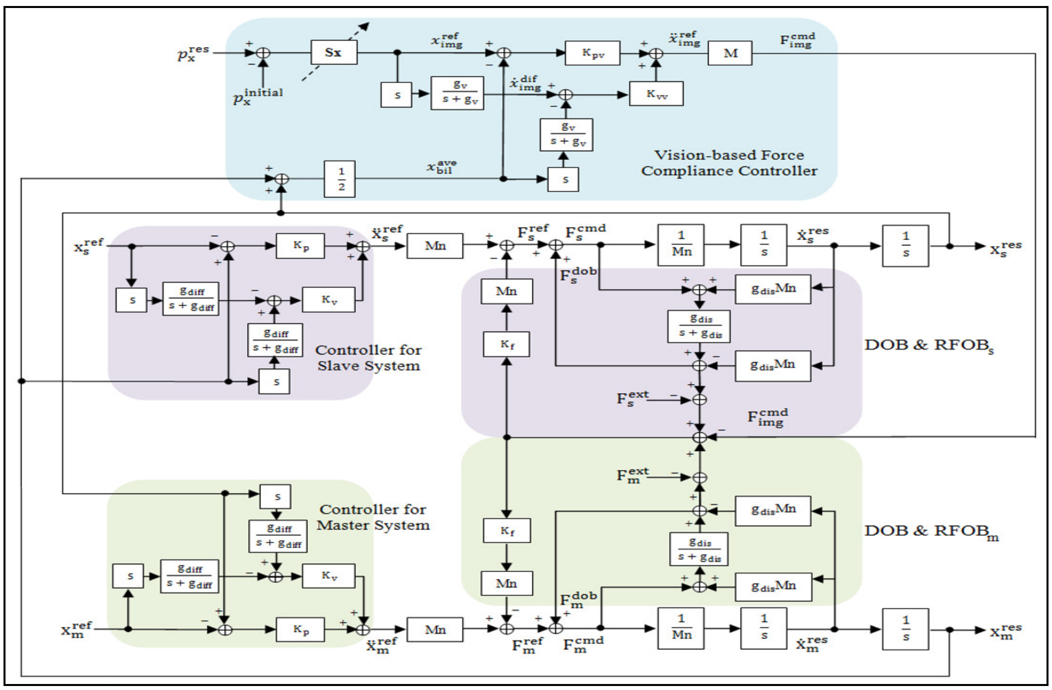

Figure 8: Overall block diagram of bilateral control system with proposed controller that can be integrated with virtual reality platform [72]

4. VIRTUAL REALITY INTEGRATION WITH BILATERAL CONTROL SYSTEM

As being stated in introduction part, this paper reviews about the VR system and its link with the haptic system. Thus, the concept of bilateral control system in haptic type of communication will be explained and how the concept will be implemented in VR operation are founded from other researchers' findings and studies about this system.

In robotic technology, haptic system is recognized to be a medium that can give force sensation to user from real environment. This system refers to the application and manipulation of touch (tactile) sensation to the interaction with computer applications, machines or human touch. Generally, haptics system can be in synchronous and asynchronous multilateral control for walking motion [68]. On the other hand, haptic information can be transmitted into two directions which is unilateral and bilateral. Unilateral is a transmission of information in one direction only without giving any feedback such as sight and hearing. While, bilateral direction is a transmission of information that comprising of action and reaction from real environment contact [69]. For a general haptics controller, a disturbance observer (DOB) is implemented for the transmission of vivid force sensation in motion control because it has wider bandwidth than force sensor [70]. DOB is able to make sampling brief and at same time increasing the observer gain [71].

By refering to Figure 8, virtual reality haptics used concept of master and slave system to achieve same interaction via disturbance observer and reaction force observer (RFOB). DOB is implemented as an acceleration control while RFOB is estimated value of external force from environment [72],[73]. Another controller known as Visual Force Disturbance Observer (VDOB) is integrated into the application of haptic bilateral system. By doing so, the study of the system performance when the generated visual force can be improved and visual information of the target object can be utilized to aware safe physical interaction [74],[75]. The integrated system was also able to distinguish between different types of geometry, materials, distance ranges and object stiffness. In short, vision based-haptic perception relies on the image information of the servoing object and manipulation of touch sense to the creation of virtual forces, allowing illusory haptic shapes with different perceived qualities, which has clear application in this technology.

For instance, bilateral control system applied as in Figure 9 when manipulator that holds the acceleration tool to measure the surface texture named as a Master and Slave is a manipulator holding a vibration actuator. Both are synchronized with sensitivity from 10Hz to 500Hz. Force and acceleration captured over amplitude and phase is made to replicate on vibration actuator [76]. This type of master-slave actuation in Haptics technology is also used in Tele-operations. As we already know, tele-operation has been studied and has capability in recovery tasks in the damaged areas and also exploitation in the extreme working environment which is difficult for mankind to approach. A tele-operation control system of construction robot (TCSCR) [77] developed from master-slave control form, is controlled by servo valve, and two joysticks for operating the robot and 3-dimensional virtual working environment as figured in Figure 10. The teleoperation technology employing virtual reality, improves the task efficiency of a conventional TCSCR by giving the operator a feeling of being at the actual operate site in real-time, system security and surpass the danger exists when operating Remote Construction Robots (RCR).

5. BENEFITS

Human beings have always been fascinated with entertainment. Feeling virtual objects gave rise to new level kind of entertainment like 6-Dimensional and 4- Dimensional movies where a person can feel the environment, training simulation, physical challenge and many more. All these haptics modulations use various actuators and devices which makes human feel the existence and sometimes the virtual world. Products like programmable keyboards, exoskeletons, desktop scales, and joystick are all designed by various manufacturers with different names. From last decade onwards, integrated VR haptics have been mostly used in medical sciences, geosciences, mechanical simulations, 3D modulation, entertainment and most importantly in education. Thereto, about 43% of global market uses haptics for human safety in vehicles, industries, manufacturing and helping the visually impaired people to read and write. All these are cost reductions in global markets and help indirectly to raise the market value of the product. Coming to one of its applications which in recent times has fascinated many researchers round the world on haptics is to store and read texture from various surfaces in different patterns and sensing them over a user affordable device.

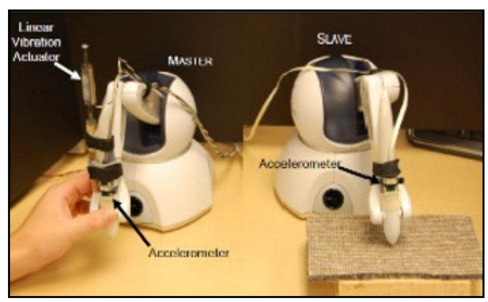

Figure 9: Phantom manipulator for texture recognition with linear vibrator [73]

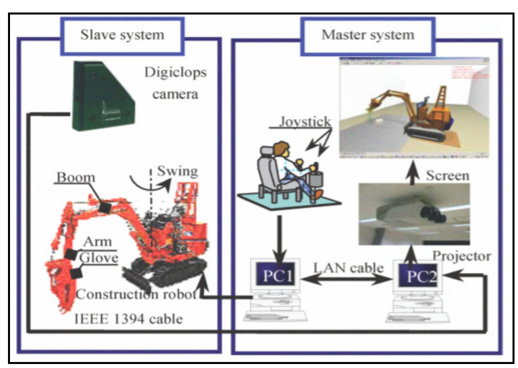

Figure 10: Schematic diagram of the tele-operation construction robot system with the virtual reality.

Everyday people come across various fascinating situations, few captured them through photography, and few feels like storing the memories not only in terms of photography but also feel like storing the sensation and pleasure of touching certain objects. But unfortunately, a photograph can never achieve a sense of touch through its in-built engineering methods. So how about making a device that can capture this feel? Sense of touch that can be recorded and stored for multiple usage as portrayed in Figure 11.

On the other side, repetitious based task supported with virtual reality technology is irrefutable especially for balance training for rehabilitation or physiotherapy. Haptic experience can be used not only for interaction with virtual environment but also for assessment of postural responses.

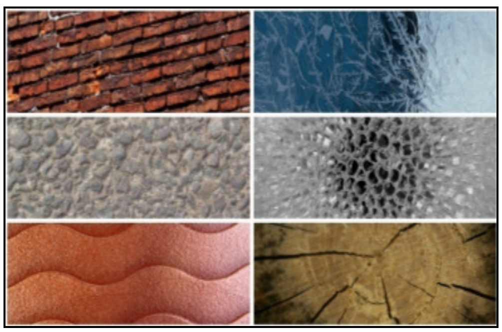

Figure 11: Different surfaces which humans feel like touching through photographs [12]

The technology ease patients and clinician as the response introduce sufficient information in terms of force feedback and image display to identify the direction and postural responses. Moreover, it helps doctors' concerning about the difficulty level of exercise to the patients as the system instantly giving necessary postural responses for every assessment. Augmented reality haptic concept obviously brings out favours to society. Haptics platform used in tele operated robots can recognize materials in hazardous conditions, identification of surface for laparoscopic surgery and inspection on damaged machines. Not just that, the concept also can be used on the data-glove for translating sign language for the deaf people [78]. VR also has applied for dental surgery, entertainment and also haptography (sense of touch through photograph). Applications of Haptics Technology is left to the imagination of human brain. Wonderful brain with million responses and size of imagination is compared with universe, will always produce better application for tomorrow's world.

6. DISCUSSION

As a final point, the area of virtual reality haptics or known as computer haptics will persist to grow and develop, helped along by research findings on perception of multimodal solutions, aided by new devices, technologies and inspired by ever complex information visualization and tactile solutions. From the reviews that have been discussed previously, VR haptics technologies are undoubtedly increasing rapidly. Based on reviews and examples in previous sections, focuses are about knowledge in both VR and haptics system. The applications of VR in haptics technology and other technical and medical field are outspread and in different range. Different from other research paper that focused only on a particular research area or a condition, this paper technically revised about the general condition of VR and covered up numerous investigation fields which applied VR concept in their studies. Expectantly, this paper will help other researcher around the world to gain understanding and better enlightenment about VR with its relation of haptics in one review paper. This is because lots of findings as well as papers are essentially contained in this review paper.

Still, there are gaps in this study field as most system especially haptics system, are having challenges on the feedback response, delay and its stability. Besides that, the work required enormous budget to develop the VR system as the sensor, actuator and materials itself are expensive and demand part replacement after it has been worn-out. This matter will be conferred in future works part in next section.

7. CONCLUSION AND FUTURE WORKS

This paper presented an overview on virtual reality haptics with its concept, applications and research works, integration with bilateral control system and the advantage it carries towards mankind and future technologies. The scope of work presented has been toward the virtual reality concept in haptics technology. In addition to experimental publications, available studies and development of research works that involve haptic virtual reality system were reviewed. These works, some with high level of evidence and others with low levels, shows the benefits of including haptic feedback in specific applications.

However, the budget to build a physical prototype and perform the simulation at the same time are quite costly as there will be some changes and mistakes during the trial. Therefore, this research gap is recommended to use the available robots in institutions' research laboratory and integrate it with conventional Virtual Robot Experimental Platform (V-REP) simulation software to create a VR environment for development of haptics communications between the real and virtual environment. V-REP is one of reliable computer software to conduct and manipulate haptics experiments using generated coding as users are able to set the parameters and specifications of the robots and applied torques desired. In subject to improve the system stability and feedback output, integration of vision-based observer as well as reaction force observer are expected to make the system respond faster and accurate. This issue will be tackled and explored in our next research.

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