Haptics: State of the Art Survey

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Abstract

This paper presents a novel approach to the understanding of Haptic and its related fields where haptics is used extensively like in display systems, communication, different types of haptic devices, and interconnection of haptic displays where virtual environment should feel like equivalent physical systems. There have been escalating research interests on areas relating to haptic modality in recent years, towards multiple fields. However, there seems to be limited studies in determining the various subfields and interfacing and related information on haptic user interfaces and its influence on the fields mentioned. This paper aims to bring forth the theory behind the essence of Haptics and its Subfields like haptic interfaces and its applications.

Keywords: *Evaluation, Haptics, Playability, User Interface***.**

1. Introduction

Haptic as an adjective relating to the tactile sense which is derived from the Greek word haptesthai, which means to touch.
A Haptic device involves physical contact between the user and the Computer. This is done through an input/output device that senses the body movements such as a joystick, data glove or bodysuit. Haptics provide the user with the sense of touch on an virtual object. This is done by synchronizing cursor and the haptic end effector movement. A robotic arm is moved in real space which is controlled by a series of motors.

To achieve the sensation which is kinesthetic haptic force must be calculated every millisecond and submitted to the haptic device. When the body parts interact with the haptic device a force is returned which is termed as force feedback depending upon which action will be performed by the system through the haptic device. Tactile feedback is used to interact with the nerve endings to feel heat, pressure and texture. Haptic interfaces are devices that enable manual interactions with virtual environments or teleoperated remote systems. They are employed for tasks that are usually performed using hands in the real world, such as manual exploration and manipulation of objects. In general, they receive motor action commands from the human user and display appropriate tactual images to the user. Such haptic interactions may or may not be accompanied the stimulation of other sensory modalities such as vision and audition.

Motivation: In the last decade we've seen an enormous increase in interest in the science of haptics. The quest for better understanding and use of haptic abilities for both humans and machines has manifested itself in heightened activity in disciplines ranging from robotics and telerobotics, to computational geometry and computer graphics, to psychophysics, cognitive science and the neurosciences.

Contribution: This paper is a fusion of multiple independent studies investigating related problems concerning haptic devices and interfaces. It also deals with Virtual Environments for Haptics in various fields such as Medicine, Gaming, Robotics, Communication, Mobile devices, Data Visualization and Multiuser Environment.

Organization: This paper is organized as follows: Section 2 deals with Literature Survey of Haptics, Section 3 deals with Algorithms in the field of Haptics, Section 4 covers Simulation Issues taken up in Haptics and Section 5 briefs about working of Haptics in Multiuser Environment and conclusions are given in Section 6.

2. Literature Survey

2.1 Haptics in Medicine

Haptic medical simulators are extensively used and experimented as a training tool, especially in the context of minimally invasive surgery [1]. Laparoscopy, endoscopy, and endovascular procedures are conducted by taking the help of commercial haptic simulators. Attention from the research community is also oriented on modeling of soft tissue deformation which is very important. With advances in computational hardware, the use of the finite element method (FEM) for tissue deformation has become a de facto standard due to its physically based continuum mechanics representation. Modeling the interaction of medical tools with deformable tissue has been studied extensively with respect to haptics.

Stroke is causing serious, long-term disabilities [2] among American adults and is also the third leading cause of death in the United States. Stroke often results in limited movements with the impaired limb even though the limb is not completely paralyzed. This loss of function, termed “learned disuse,” is most obvious during the early post-injury period but, can improve with rehabilitation therapy. Studies have shown that the potential for the degree of functional recovery after stroke involves not only the level of initial impairment but the amount, type and intensity of practice available to the patient during the recovery process.

In rehabilitation therapy it is important to maintain patients’ motivation and engage them to confront with a repetitive series of retraining challenges. In this regard, virtual reality (VR)-based rehabilitation systems with an understanding of gaming features and their integration into treating patients enhances patients’ motivation in a useful direction explores possible effect on stroke rehabilitation. Novel VR environments may allow patients to be motivated by gaining success in virtual skills that build towards actual skills even when the actual skills are still limited. Incorporating haptics (rendering of the sensation of shape and texture) into the virtual test environments may enable patients to practice every day skills in which real objects are simulated and their daily routine is made comfortable.

A technology has been introduced and presented with preliminary results [3], with an integrated technology platform for creating an virtual exercise environment for a number of modalities. This must be conveyed for an effective haptic medical therapy session to take place during stroke treatment. In addition to the training task to be performed with the haptic device, a communication channel must exist between the therapist and the patients.

With the enhanced capability of the internet it is now possible to transmit all the relevant information to handle large digital media information. Recently, broadband internet connections present a viable and cost-effective way to send and receive audio, video and haptic streams. An Interface called as Audio Peer aims to provide a foundation for collaboration tools that will enable novel interactive applications. Audio Peer, which is a multi-party voice conferencing system, is designed to allow individuals and groups to communicate. The goal here is to provide users with an interactive audio experience based on a platform that is scalable, practical, integratable and extensible with new features. The integration of a telehaptic system with remote voice conferencing presents a powerful opportunity to provide high quality and effective healthcare in a cost-effective manner.

A Blind Aid system [4] has been made that provides VE maps for people who are blind and consists of application software running on a personal computer equipped with a haptic device and stereo headphones. The haptic device that was used in the experiments was a Desktop Phantom® (Sensable Technologies) and they used Sennheiser HD580 headphones.

In the current implementation, the virtual space is bounded by two horizontal planes: *floor* and *ceiling*. VE developers create virtual maps by defining static virtual objects at fixed locations within this horizontal space. All objects extend uniformly from floor to ceiling and are represented by a small set of standard object types comprised of simple geometric shapes with various properties. For example, the *wall* type is a vertical rectangular plane that is used to represent walls. All walls have the same graphic and haptic properties, but individual walls may be associated with unique identifying sounds.

Another example, the *rectangle* type (a right rectangular prism, or box shape, with tops and bottoms parallel to the floor), may be used to represent a wide range of real world objects (e.g., tables, chairs). Each *rectangle* object has its own individual graphic, audio, and haptic properties. A single object in the VE may also be represented by more than one instance of a given virtual object type and possibly as a combination of instances of multiple types. Other standard object types include: *windows*, *private doors*, *public doors*, and arbitrary *vertical boundaries* (all of the preceding are vertical planes similar to walls, but with potentially different properties), *cylinders* (similar to the *rectangle* type), and *ground textures* which define regions of texture on the floor.

2.2 Haptics in Gaming and Robotics

According to [5] Gamers just want to have fun. Some factors of a game which contributes to the experience that keeps the player coming back for more are: a compelling storyline, challenging scenarios, amazing graphics, exciting online play, and good game design are just a few. Some special Rumble effects used properly can also greatly enhance the gaming experience and increase entertainment. Though some have criticized rumble as a feedback only, reactionary feature, it supplies a physical connection to the game that cannot be furnished through an input-only device.

Touch feedback can reveal crucial information that can be neither seen nor heard. Rumble is great when it’s carefully designed and closely timed to the player’s actions or to onscreen events and/or sounds. Gamers say it’s awesome when it’s realistic — when a machine gun doesn’t purr like a kitten but instead rattles your teeth! And rumble is also very compelling when it heightens emotions and involves the player at a deeper level. The 11,000+ gamers surveyed were asked about the best uses of rumble in console video games. The verbatim comments that follow reveal that rumble is vital, and why that is so: it adds realism, engagement, and fun to many game genres. In addition, the data shows that rumble appeals to gamers of both genders and a wide range of ages.

Similar to Human beings robots also should have sense of touch since a well-performing robot must be able to interact and identify objects in its environments [6]. It is also important as it supports, and sometimes substitutes, the visual modality during recognition of objects. Like humans, robots need to perceive properties like shape, size, texture, and hardness and also should be able to discriminate between individual objects by the sense of touch.

Using passive touch, humans are able to gather information by receptors sensitive to pressure, heat, touch, and pain and perhaps to determine the shape of the explored object as well. However, a more active exploration of the object enables cutaneous information from the skin and proprioceptive information from the joints to be combined, thereby allowing a larger amount of information about shape and size to be collected. It also makes the perception of texture possible. Together, these processes come under the ambit of haptic perception, which involves sensory as well as motor systems.

Two important sub modalities in haptic perception are texture and hardness perception. In noninteractive tasks, the estimation of properties, like the size and the shape of an external object, are, often to a large extent, based on vision only, and haptic perception is only employed when visual information about the object is not reliable. This might happen, for example, at bad-lighting conditions or when the object is more or less occluded. Haptic sub modalities, like texture and hardness perception, are different in this respect. These sub modalities are especially important because they provide information about the outer world that is unavailable for all other perception channels.

Modeling of haptic perception and the implementation of haptic perception in robots are two neglected areas of research. Research has mainly focused on grasping and objects manipulation and many models of hand control have been focused on the motor aspect rather than on haptic perception although there are some exceptions. This paper reviews a number of self-organizing robot systems that are able to extract features from haptic sensory information. They are all based on self-organizing maps (SOMs). First, the Lund University Cognitive Science (LUCS) haptic-hand II has been presented which is based on the three-fingered robot hand which successfully identifies the shape of objects.

These systems explore each object with a sequence of grasps while superimposing the information from individual grasps after cross-coding of proprioceptive information for different parts of the hand and the registrations of tactile sensors. The cross-coding is done by employing either the tensor-product operation or a novel self-organizing neural network called the tensor multiple-peak SOM (T-MPSOM). Second a system based on proprioception and an anthropomorphic robot hand, i.e., the LUCS haptic-hand III is presented. This system is able to map objects both according to shape and size. Next systems that are able to extract and combine the properties texture and hardness from explored materials has been described. The systems presented in this paper have been implemented using the modeling framework Ikaros.

Port-Hamiltonian systems have always been described and used in continuous time which is not sufficient for real time control applications like haptics and telemanipulation. These results can be easily extended to telemanipulation using ideas based on geometric scattering and for time varying time delays like in Internet applications.

Haptics and Tele-manipulation are both characterized by the physical interaction of humans with robotic systems. The importance of passivity, port based models and the description of the interaction using physical elements as springs and dampers have been widely recognized in the literature due to the fact that humans are highly unstructured. Port-Hamiltonian system theory is a reasonable novel theory which allows to analyze physical systems interaction in a much more general way that it would be possible with simple physical models. Especially for robotics, where geometry plays an important role, port-Hamiltonian systems can be very useful.

An algorithm is presented which is capable of simulating continuous time systems expressed in Port Hamiltonian form, preserving system passivity [7]. The method considers linear systems but, being the stability criteria based on passivity, can be extended to nonlinear system. Moreover, the design of an element able to passively interconnect two systems running at different sample times is presented.

In particular, in this paper, the authors have described an algorithm which is able to simulate in discrete time a continuous-time system preserving its passivity properties. Main feature of this algorithm is that the passivity properties of the continuous-time system are maintained also if it is executed at low-frequency. They have also presented an element, called the *Passive Sample and Hold*, able to passively connect simulated physical systems running at different frequencies. In particular, this element allows connecting in an energy-consistent manner the HI control loop, running at high frequency, with the VE simulation algorithm, running typically at lower frequencies.

Robots can manipulate objects based solely on the sense of touch **[**8**],** this has been proved time and again. Global initial uncertainty is assumed in 6-DOF. To overcome the computational challenge, a principled approach has been s proposed—termed Scaling Series (SS)—that solves the full global 6DOF localization problem efficiently (~1 s) and reliably (=99%). The approach is a Bayesian Monte Carlo technique coupled with annealing. It performs multiple iterations over the data, gradually scaling the precision from low to high. For each iteration, the number of particles is selected automatically based on the complexity of the annealed posterior.

It has been observed that Scaling Series works in both fully constrained unimodal scenarios and under constrained multimodal scenarios. The latter arise at early stages of tactile exploration, when insufficient data have been collected to fully constrain the problem. To check the constraints free-standing objects were considered, which can move during tactile exploration. Less work and analysis has been addressed for a full 6-DOF Bayesian estimation which needs to be looked into.

In addition, an analytical measurement model for tactile perception that can be used for any object represented as a polygonal mesh has been analyzed. Unlike sampling-based models, this model can be computed quickly at run time and does not require training ahead of time. Due to its differentiability, the presented model allows for efficient estimation. They provided a sound theoretical foundation for the approach, including proofs of convergence and considerations for parameter selection. They also made an in-depth evaluation of the algorithm features and significantly give information about previous work.

2.3 Haptics in Communication

Information transmission capability has been studied [9] and assessed by the mobile on virtual reality systems. This is necessary as there is an increasing interest in the design of haptic signals for conveying more than digital information on mobile and wearable displays like vibratese, haptic icons, tactile melodies, tactons and tactor arrays. Other metrics, such as task completion time and detection or discrimination thresholds, have also been widely used when studying haptic displays.

All these performance metrics can provide valuable information to designers of displays, but they also have their limitations when performance needs to be assessed in terms of communication efficiency. For example, task completion time is confounded with performance level by the participants' speed-accuracy tradeoff criteria, and therefore, the fastest user may not always be the best one. A higher localization error will result from cramming more tactors into the same area on the skin. It is very difficult for a device designer to guess maximum number of tactors on a haptic display by considering error rate alone.
(Refer to Table 1) Discrimination thresholds carry the units of the physical parameters involved and cannot be meaningfully compared

Table 1: Different types of Haptic Display Devices

Display	Features
Head Mounted Display	Panoramic view
Auto-Stereo Display	No glasses
Shutter Glasses	Wider range of sweet spot

(e.g., it is not clear whether a 0.5 N force magnitude discrimination threshold is better or worse than a 23-degree force direction discrimination threshold). And the limitations of questionnaires have been addressed by Slater. Information measures, however, have the potential to overcome many of the above-mentioned limitations for assessing the information transmission capabilities of visual, auditory, haptic as well as multisensory information displays.

Static information transfer (IT) quantifies the amount by which uncertainty has been reduced. It is useful for characterizing performance when the task involves the correct identification of one stimulus from a set of alternatives. The IT measure is usually independent of the task context (e.g., increasing the number of stimuli in an identification task will not increase the overall information transfer once channel capability has been reached).

A study on using scattering base communication channels concludes that local and remote sides exchange only velocity and force information and this can cause the rise of a position error between master and slave robots [10]. Discrete scattering is used to build a control scheme for telemanipulation of port-Hamiltonian systems over a packet switched communication network. A strategy for passively dealing with the phenomena of packets loss has been proposed. Loosely speaking when an expected packet is not received, it is replaced by null packets.

Using this strategy, when a packet is lost, its corresponding energy content is dissipated. In this way, in free motion, some of the energy that has to be delivered to the slave side in order to move the slave robot accordingly with the master is lost and, therefore, at steady state, the position of the slave can be different from that of the master. Here port-Hamiltonian based bilateral teleoperators have been considered general representation of passivity based bilateral telemanipulation systems. The port-Hamiltonian framework allows to model both linear and nonlinear passivity based telemanipulation systems.

2.4 Haptics in Mobile devices

The two factors which influence the perception of strength of a mobile were examined: the weight of the device and the frequency of the driving vibration [11]. Since there is a clear correlation between these factors and the perception of vibration

strength, findings suggest that designers of mobile devices need to take them into account.
The first experiment was designed to determine the subjective equivalence of vibration magnitude for devices having different weights. While manipulating several mobile devices of varying weights, it was observed that the perceived vibration strength varied for the same measured acceleration magnitudes. The existence of a weight-vibration perceptual interaction was then hypothesized from the results of a pilot experiment.

A second experiment was motivated by the trend seen in the industry to use higher vibration frequencies. This is a result of using the peak-to-peak acceleration as the only measurement of vibration strength and not considering the take an essential part in the global learning process at school. Even if it is easy to transpose schoolbooks text into Braille, the various pictures, maps and graphics, which illustrate these schoolbooks underlying driving frequency. As the phone size decreases, designers choose smaller motors that can achieve the same magnitude levels by spinning at a faster rate. To establish the relationship between perceived vibration strength and frequency, a magnitude matching test was performed targeting the conditions found for typical mobile devices. It was expected that the results would generally agree with those of previous studies indicating that higher frequencies require higher accelerations to achieve the same perceived strength.

2.5 Haptics in Data Visualization

A study on Haptic Data Visualization (HDV) [12] and the underlying model is more abstract and encodes, not a physical environment, but numerical values or an abstract mathematical concept. The specific aim of HDV is that the user understands data that are being represented by the haptic model; not only does the user feel the model, but in doing so realizes value and can draw conclusions from that data. For instance, a model representing a line graph of stock market data would aid the user in understanding how the stock values change over time, whether increasing or decreasing. A user may also be able to perceive maximum or minimum values or points of crossover or inflection on the graph. Values may be realized through different ways, e.g., larger values could be mapped to high frequencies, with low values to low-frequency vibrations.

A comprehensive review and classification of designs for HDV has been provided here and also it provides a snapshot of the state of the art, and thus, demonstrates areas of future work. The work is categorized by the representation of the data: charts, maps, signs, networks, diagrams, tables, and images. This categorization was chosen because it distinguishes the various types of design, enabling the methods to be uniquely classified. For example, the structure of a network presentation, which details associated data nodes, is very different to geographic information that is displayed on a map in two dimensions. For each different form, a design has been presented along with the, the technologies used, and any issues or challenges with the presentation.

Schoolbooks are still inaccessible for people with visual impairment [13]. New pedagogical methods rely increasingly on illustrations to convey pedagogical content, partly since they are easier to produce. Schoolbooks have a lot more pictures, often two or three of them on each page, whatever the subject of the book. Moreover, multimedia support is more and more used in classrooms to present some information to the students, while the literacy of people with visual impairment must rely on self-access to paper documents.

Even if they can access digital text with screen readers, speech synthesizers and special printers, they still have problem accessing the numerous digital illustrations Special printers and adapted software now give students with visual impairment access to Braille, but there is still a lot of work to do for the accessibility of illustrations. Most methods to give access to images currently use manual transposition and special papers, such as embossed or thermoform paper [14].

The requirements for tactile display devices to tackle tactile stimulation which are imposed by physiology of touch, ergonomics, and handheld compatibility are surveyed [15]. The perfect tactile device would be able to display a wide range of tactile sensations, including thermal information; it would combine lightness, compactness, and low power consumption. More practically, the devices limited to vibrotactile sensations can be compared with respect to criteria like their frequency range, their resolution and the dynamic range of their stimulation effects comparatively to their sensation thresholds.

Many tactile display devices were proposed during the last few decades; most of them were laboratory devices, only dedicated to the understanding of the mechanisms of touch. The main obstacles to their use for other applications were their size, their level of sophistication and the price of their components. However, some tactile devices bound to operate on specific applications were developed and integrated in systems able to benefit from tactile rendering. Two devices were proposed for teletaction applications in laparoscopic surgery; they were based on pneumatic actuation and micromotors. A few devices also stood out for their relative lightness and compactness. Different families of tactile devices can be identified. The first one regroups the devices that control the roughness or sliding friction of their active surface.

They provide delimited vibrations to the skin, mostly through an array of actuators. Most of them provide vertical vibrations, with variable amplitudes and frequencies of vibration. The devices with the better spatial resolutions (reaching 1 mm) and large frequency ranges, up to 400 Hz are often too bulky for any commercial development. Some displays stand out from this family of devices. It is the case of the STReSS, a prototype based on piezoelectric comb arrays that allows shear forces on the fingertip. It presents a high refresh rate (700 Hz) and a millimetric resolution. Finally, a combination of normal and tangential actuation was proposed by Caldwell, with a prototype decoupling its actuation mechanisms for the reproduction of pressure or textures (normal actuation) and roughness (lateral actuation).

The effect of tactor spacing and array size of vertically moving pin tactile arrays on human tactile perception is quantified effectively [16]. This was achieved through psychophysical experiments that measured the angle discrimination threshold of a small ridge and the 2D shape recognition performance while exploring edge- based patterns with different passive (nonactuated) tactile arrays. The study considers an active exploration and patterns smaller than the finger pad. The active exploration is carried out at an adjustable speed, considering that based on instinct or past experience the subjects choose a speed that seems optimal for the tactile recognition or discrimination tasks .

The main difference of this study with those presented by and is that this study was executed using active touch exploration. During the exploration the motion and velocity of the finger pad were monitored. In addition, as mention above, this work also investigates the angle discrimination thresholds for small ridges. In order to decouple the possible effect of the pin diameter variation this work makes used of pins of equal diameter for the entire pin spacing and array size cases. Summarizing, this study investigates the following hypothesis, which is related to the human tactile perception through tactile array displays.

Hypothesis: A low density arrangement of actuators/sensors with a tactor spacing around 2 mm arranged within an area of 1 cm^2 can provide sufficient tactile information while playing back or sensing small-scale and edge-based tactile patterns.

3. Algorithms in Haptics

From past several years, many attempts have been made to quantify the benefits of a haptic algorithm [17]. Theoretical approaches tried to quantify the time complexity of different algorithms. Although this leads to a better understanding of the algorithms' performance, it does not allow for the comparison of two algorithms with the same time complexity. Furthermore, due to the behavior of the end user, some optimizations are difficult to predict. Thus, these theoretical findings should be complemented with real-life measurements in order to know the exact behavior of an algorithm. But this is still not enough for a valid Comparison.

One of the most important flaws in current evaluation methods, besides the lack of exact numerical results, is that they do not provide the algorithms with the same data. The haptic load is measured while interacting in real-time with the virtual environment. This means that the algorithms being compared receive different input. Hence, unintentionally, both algorithms are not compared in an equal manner. Moreover, Anderson and Brown compare two object rendering algorithms which are implemented in two different APIs. This adds the scene graph performance into the measurement, which may again result in an unintentional side-effect of the measurement method with implications for the results.

This problem was addressed by presenting the same real-world data to different algorithms. In an interactive session, in which users explore a virtual object with a haptic device (in this case, a PHANToM device), the device's position and velocity are recorded for each loop. This data is then passed on as input for the other haptic algorithms. Different variables such as the time needed to execute one haptic loop, are recorded and compared. An example of an empirical evaluation in order to assess the validity of this approach has also been given.

Haptic and visual algorithms are created to simulate bone cutting tools for voxel-based bone material as it has improved stability. The Voxmap point-shell haptic algorithm [18] can be felt with the haptic device during haptic interactions. Additional testing will allow us to quantify the improvements. The maximum number of haptic points supported by a tool bit (while maintaining haptic stability) will vary with different computer systems. The 1ms haptic loop constraint only allows small force calculation time fluctuations. The multi-rate haptic interface (Refer to Table 2) helps maintain stable haptic interactions across different systems without adjusting tool bits' point-shells. Using texture based volume rendering to display the bone in real time and performing shading calculations on the GPU helps free up the CPU for other simulator tasks.

The described algorithms have been tested for drilling on a voxelized block. It will be possible to generate the voxmap directly from the voxel discretization of patient-specific 3D CT and MR Datasets to generate virtual patients for a surgical simulator.

Several surgical tools that are typically used during a craniotomy have been simulated. Separation of the haptic and erosion points enables modeling the different types of tool bits. Realistic 3D models are created from real surgical tools and controlled by the haptic device during their use.To create

Table 2. Workspace sizes of haptic interface devices

Device	Width [mm]	Height [mm]	Depth [mm]
Omni	160	120	70
Desktop	160	120	120
SPIDAR	200	120	200
Falcon	75	75	75

realistic tools, tuning the erosion factors and haptic response based on experimental data and/or expert feedback can be done. The generality of the described algorithms will make it possible to create additional virtual tools.

In a wave variable based algorithm a method is presented [19] in which a Smith Predictor is used to reduce the mismatch in time by correcting the incoming wave variable with the predicted future value of that variable without loss of passivity. Several algorithms based on the haptic interaction with a local model of the remote environment in the time domain, generally referred to as Impedance Reflection algorithms, have already been proposed, but offer no passivity of the telemanipulation chain which is a desirable property as it guarantees stability. A first attempt to extend such a transparency strategy with a passivity property is described in where a time domain Passivity Observer is used to adapt the locally computed feedback force based on the actual measured, but delayed, interaction force to make the system passive. Also interesting is the work, where an online energy bounding algorithm is presented for a spring-damper controller at the slave side.

In the opinion of the authors the most abstract view of an algorithm which combines the discussed transparency and passivity properties would be a two-layer structure as shown in The Transparency Layer tries to satisfy the goals of the telemanipulation chain: movement synchronization on the slave side and force reflection on the master side, by computing a desired torque. The Passivity Layer on the other hand has to make sure that the commands originating from the Transparency Layer do not violate the passivity condition. The benefit of this strict separation in layers is that the strategy used to ensure optimal transparency does not depend on the strategy used to ensure passivity and vice versa.

Most schemes only incorporate a single, possibly mixed layer and as a result a single two-way communication connection between the master and slave system. In this algorithm, however, the passivity and transparency are dealt with in separate layers and therefore can easily define two two-way communication channels between the master and slave system. One channel is used to communicate energy exchange related information between the Passivity Layers and the other to communicate information related to the behavior between the Transparency Layers.

This is the lowest-level control layer, whose only concern is to maintain passivity of the telemanipulation chain. Every movement the slave device makes will have an associated energetic cost and this energy will therefore have to be present at the slave side at the moment the movement is executed. In order to maintain passivity, the same energy will also have to be injected previously by the user at the master side. This clearly requires the transport of energy from the master to the slave system. To this end, the concept of a lossless energy tank is introduced in the Passivity Layer at both the master and the slave side, which can exchange energy.

As far as energy exchange is concerned, the possibility to send energy quanta from master to slave can be considered when there is energy available in the tank at that side and vice versa in the form of packets containing the amount of energy sent. When these packages arrive at the other side they are stored in a receiving queue. Both master and slave can implement completely asynchronously at any instant of time.

It has been observed that Haptic interaction, unlike its visual counterpart, is inherently a local process [20]. In other words, only a small number of nearby faces need to go through subsequent collision detection processes once a contact location is found. In order to select only the necessary faces, it is critical to know what the user intends to do at that moment. Unable to measure the user’s intention, a velocity signal often comes in as the best predictor for it. Using a motion based prediction method; it is possible to choose a good local model exhibiting both compactness and completeness.

Implementing the prediction based method requires a proper data structure for local navigation. A graph describing the parallel connection among the vertices is thus suitable for the purpose of neighborhood query. Simply linking the incident vertices and faces is one way to encode topology, such as a list of incident primitives maintained by each vertex and face. More sophisticated methods, however, use edges as the building block since most topological information resides in them.

Although a graph can describe the topology of the model, it needs to be combined with another hierarchical structure for use in a haptics application. A collision checking routine extensively uses the tree structure to quickly locate the point of contact. Merging these two very different structures is equivalent to connecting the leaf nodes of the model hierarchy in such a way that correctly depicts the topology of the model as illustrated. A combined data structure, thus, can handle both collision and neighborhood search query in an efficient manner.

Various tree and graph structures including a sphere tree, OBB, and various edge-based graphs are already well known for their efficient handling of search queries. The Sphere tree and the

Quadedge data structure, among others, are simple yet elegant representations of the model for the purpose of implementing haptic algorithms. A sphere is the simplest object in three dimensional spaces and requires only a single distance computation between each object for the collision query. Abounding sphere tree is constructed from the collection of spheres each enclosing a single face of the model. Each leaf sphere is paired up with a nearby sphere and enclosed by a bigger sphere. Such a hierarchy simplifies the collision checking process by pruning unnecessary branches from the search process and as a result reduces the cost associated with searching. On the other hand, the Quadedge data structure is a graph structure with a compact and elegant representation for the topology of the model.

It is claimed that the elements of a typical haptic interface system include the VE, the virtual coupling network, the haptic device controller, the haptic device, and the human operator [21]. Many of the input and output variables of these elements of haptic interface systems can be measured by computer and the conjugate variables which define power flow in such a computer system are sampled time values. The haptic interface or teleoperator system is assumed to take a position as an input, and computes force as its output. Typically, this position input comes from position sensors such as encoders, and the computed force value is applied to the environment and/or operator through motors controlled directly by the output of a zero-order hold (ZOH).

In this paper, a more accurate time-domain passivity-control approach is proposed, considering the velocity change during one sample time. The actual energy output can be measured precisely with the sampled time passivity measure, but actual energy output can only be known after the energy is already produced. To avoid the active behavior, a new PO has been proposed, combining both predictive and accurate features, and designed the PC based on the new PO. Sampled and continuous time energy behavior were analyzed and it was proved that the sampled passive system is at least stable, even though it is not passive in continuous time.

4. Simulation Issues in haptics

Virtual Reality simulations of two different types of billiards game are presented by [22]. In the first approach a haptic device has been used to provide the user with an interactive and realistic interaction. The force feedback (Refer to Table 3) is provided by means of a commercial haptic interface and in this way it is possible to strike the billiard ball and to feel the contact between cue and ball.

The second, in order to overcome the limitations due to the use of a commercial haptic device which has not been specifically designed for the billiards game, uses a different type of Simulation, which has been developed using a real billiard cue. By means of visual maker detection system the cue movements are replicated in the virtual environment, but no force feedback is provided to the player.

Table 3: Different types of Haptic Force FeedBack Devices

Tracking / Sensing System	**Features**
Magnetic Tracking System	Multiple points 6DOF data
Visual Sensing System	Visual hull data

Billiards game simulations have been developed both with and without the force feedback sensation with three degrees of freedom with haptic feedback along the translation. Visual markers are widely used in Augmented Reality (AR) applications. Currently there are several different types of based marker tracking systems (Refer to Table 4).

In the first type of simulation of the billiards game, in order to make the game as interactive and realistic as possible for the user, a force feedback is provided and it is possible to strike the billiard ball and to feel the contact between cue and ball. By means of a commercial haptic interface (PHANTOM Omni) a force feedback is provided, thus rendering the interaction realistic and exciting to the user.

In the game simulation it is possible to distinguish three different types of modeling: graphical, physical and haptic. The graphical modeling consists of a set of 3D objects built using 3D Studio and imported into the XVR development environment where they are managed using the XVR scenegraph. An example of billiards with five skittles has been implemented. Since in the real game it is possible to use your left hand when aiming and striking the ball, in the play modality it is possible to fix the cue movement in the desired direction in order to allow a more careful aim and a more stable interaction in the virtual environment. In addition it is possible to choose the force amplification with which the ball is hit.

Each object of the scene graph is modeled from the physical point of view defining the geometry, the mass, the inertia, the stiffness and the contact friction with another one.The ODE library is used to carry out the physical modeling definition and to define the dynamics for simulating the billiards game. Regarding the haptic modeling of the objects that are present in the virtual scene, the utilization of the OpenHaptics library makes it possible to exercise control at a lower level of the haptic interface. The cue is modeled as a rigid body and, in the play modality, its position and orientation are linked, using a spring-damper system, to the position and orientation of the haptic interface stylus.

Table 4: Different types of Haptic Tracking/ Sensing Devices

Force Feedback Device	Features
PHANToM	Single tip or dual tips operation
Novint Falcon haptic Device	Transitional 3 DOF device
SPIDAR	Point-type haptic interface device
CyberGrasp	Hand operation
sigma.x	Bi-manual teleoperation console design.
omega.3	Renders crisp contact forces

The limitations of the simulation are due to the use of a commercial haptic device which has not been specifically designed for the billiards game.Because of the limited workspace of the haptic device used, it is not possible to perform some shots, which, in the real game, require wide movements in order to be carried out. In addition, it is not possible to use your left hand in order to stabilize the cue and to obtain a more precise stroke, as would happen in a real game of billiards. For this reason some modifications have been introduced in the simulation; in particular it is possible to fix the chosen direction of the cue during the strike and also to decide on the force amplification with which to hit the billiard ball.

5. Haptics in Multiuser Environment

[23] Proposed two peer-to-peer architectures and studied their performance. However, no stability analysis was provided and the virtual coupling gains were selected by experimentation. A mathematical model of the system was developed based on multi-rate modeling techniques. Although the work primarily targeted haptic interaction over Local Area Net works (LAN), stability margins of the system were compared to that of the centralized architecture for computation/network delays in the order of 1 to 3 network sample times (8-24ms). The communication delay over a Wide Area Network (WAN) such as the Internet depends on factors such as geographical distribution of the users and the network traffic and can be larger than these numbers.

Moreover, depending on the network condition, the packet transmission rate remains around 100-200Hz, below the 1 kHz update rate required for high-fidelity haptic rendering of rigid objects. These limitations can degrade the transparency of networked haptic interactions over the Internet and may even result in instability. The concept of passivity was employed into guarantee stability of bilateral teleoperation with time delay. Wave variable transformation and passivity based techniques were utilized in for multi-user haptic rendering. While these methods can ensure the stability of haptic interaction, they usually yield poor transparency due to their inherent conservatism.

This work builds upon related work in distributed networked haptics with a stronger emphasis on the effect of time delay in the context of Internet communication. To this end, measures are defined to quantify the transparency of haptic simulation in the distributed control architecture. Using these performance measures, an optimization problem is formulated to obtain a set of control gains that optimize the transparency subject to stability constraints. A model-based predictor is also introduced to compensate for the negative effects of delay on stability and transparency of the simulation.

Port-Hamiltonian based bilateral teleoperators are discussed as a quite general representation of passivity based bilateral telemanipulation systems [24]. The port-Hamiltonian framework allows modeling both linear and nonlinear passivity based telemanipulation systems. A controller that allows to passively compensating the steady state position errors, which may arise both during contact tasks and in free motion can be obtained. Roughly a port-Hamiltonian system is made up of a set of energy processing elements (energy storing, energy dissipating and sources of energy) that exchange energy through a set of energy paths which form a power preserving interconnection along which energy is neither stored nor dissipated but simply transferred.

More formally, port-Hamiltonian systems are defined on the state manifold of energy Variables X and they are characterized by a Hamiltonian energy function $H: X \rightarrow R$, expressing the stored energy, and by a Dirac structure D, representing the internal energetic interconnections. The system is endowed with a so-called *power port* that is represented by a pair of dual power variables $(e, f) \in V * \times V$ called effort and flow respectively. This port is used to exchange energy with the system; the power supplied through a port is equal to $eT f$.

6. Conclusions

We have tried to bring out the theoretical approach to the understanding of Haptic sub fields where haptics is used extensively. Hope this work satisfies the people who are pursuing research in areas relating to haptic modality. This work will be benefiting due to its extensive studies in determining the concepts of various subfields in Haptics, their interfaces and related information. This paper aims to bring forth the essence of haptic interfaces and its applications. Because of the successful approaches in the systems presented in this paper, in the near future, we will continue our research in haptic perception and rendering by trying to merge the findings from all these systems.

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