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Latest Developments in Haptics Technology

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ABSTRACT-- *Haptic Technology has been discussed and also applied in industry in all domains. This paper reviews the latest in the field over the last three years. The technology starts with basics of touch, tactile and vicrotactile methods with the first task of grasp, in general, be it any application. Various hand-wearable devices with various combinations of techniques and devices have been used along with haptics till date. Many of these have been discussed in the paper. Also, we have tried to club similar work at one place chronologically to see the progress in the similar area over good labs worldwide, through peer-reviewed research papers. The paper aims at exploring the wide success accomplished in haptic technology and interfacing through various permutation combinations at different levels of device manufacture, especially in medical domain.*

Keywords-- *Latest Developments in Haptics Technology*

I. INTRODUCTION

Human- Computer interaction has seen technological advancements to its best. However, the missing component of tangibility has been taken care by Haptic technology in the recent years. This man-machine collaboration exhibits many benefits but as far as clinical benefits are assumed, there is still a long way to go. This somatic sense is indispensable for our sensory system and incorporating that into a man-machine system on simulation and practical cases has challenges. Surgical robots have not invaded operating rooms in general and another several years of research on its advancement would cost very high. Some constraints to be attempted are mandatory to prevent a robot from moving a fraction of inch into a forbidden region. Stability from a control instrumentation perspective is a big task to be achieved as contact between two rigid surfaces always has chattering instability. A controller which showed stability in soft tissue contacts may not behave the same in contact with a bone. Human decision, neuromuscular delays, communication delays, user's grasp are some parameters which may aggravate or cause instability. The requirement is thus much complex with passivity inspite of destabilizing interactions and somewhat unpredicted environment. Even in case of virtual environment based upon simulations. In addition, the bidirectional requirements make the design more demanding and notorious. These energy tasks and vagueness are natural control artifacts like vibrations and impedance mismatch. The expertise of the operator/ surgeon remains the limiting factor ofcourse. However, the benefits of robotic surgery which include minimal invasion reduced tissue trauma, reduced blood loss, decreased risk of infection, less pain, less recovery time, etc. remain the driving force in the research in MIS. Since, the absence of haptic feedback is a potential cause of error in MIS, researchers have been working on applications of haptics at small and large levels. Needle insertion in the

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absence of real time imaging, palpation, tissue stiffness mapping and microsurgery tasks are typical examples [1]. A new neural network based framework for supervised training of neurorehabilitation system post-stroke was also studied and used for simulation of motor ability of a patient [23].

II. VIBROTACTILE HAPTIC FEEDBACK

Vibrotactile haptic feedback experiments conducted over some period showed improvement in ability to recognize objects and textures with increased success rate over the spread of time. The purpose was to mimic the tactile receptors in human skin when the person cannot see. Also, it gives freedom from constant visual attention required by amputees. Along with the development of a functional haptic feedback system, the authors have stressed upon the need of training using dynamic feedback. The flow of components in the basic instrumentation involves sensors, convertors, amplifiers and detectors. The static data includes the pressure related information of a particular sensor, while the dynamic data relates to rapidly changing vibrations on the surface of a sensor. The short-term experimental results showed an improvement in recognizing the capabilities of participants / subjects; while the long-term objective is to give amputees the sense of touch. The robotic hand was given the task of texture recognition and was subjected to training procedure also. The authors have suggested many future directions too in their research work, involving real amputees for development of prosthetic arm, wider range of skin, etc. [2]. Another paper introduces the concept of Dynamic Passive Haptic Feedback. This a mixture of Active Haptic Feedback and Passive Haptic Feedback. Basically, it combines the strengths of the two methods. A prototype had been developed to study and increase the perception sensitivity for objects using virtual reality interactions. The device picks up virtual objects of various weights and investigates continuous variations in object thickness and length, and also picks the virtual objects in virtual environment [13]. A similar work was done by Naoki Takizawa et al for the development of another haptic interface device which was encountered-type and could generate the physical characteristics or shape of a rigid 3 D virtual object by utilizing specialized balloons. A linear actuator could change the rigidity of a balloon, and hence volume change or the exposed surface area could also be controlled. The future aspects of such work include that on a surgery simulator for learning and training of robotic surgery [16]. Another paper gives the design and also validate an ungrounded reality system which was haptic-augmented for displaying friction and roughness of a 3D object [22]. Two hand-held joysticks were used in a separate experimental set up, to compare performance for investigating the location of stimulation using vibrotactile methods [27].

III. EFFECT OF VELOCITY AND FRICTION

The authors, in a research work, investigated the tactile flow using an arrangement of vibration for enhanced forward velocity of motion of robotic hand. An optical flow is simultaneously applied in peripheral vision. The experimental set up to evaluate the effects of touch stimuli included eleven normal participants who gave an ethical consent statement for participating in the experiment; a specific tactile stimulator and controllers. The self-motion was assessed by calculating the forward velocity and the participants reported a faster test stimulus with increase in visual velocity. The results exhibited that the forward self-motion can be modulated by optical flow. Again twelve participants were selected for subsequent analysis, the results of which showed that the magnitude of modulation of velocity flow is insignificantly strong in comparison to the desired strength [3]. The proximal modality or the sense of touch was again experimented in detail to increase touch sensation by sensing illusions in 3 D, outside the body. These findings are quite valuable for haptic perception and applications research [18]. Input-to-state stable (ISS) approach had also been utilized for studying haptic interaction in virtual environment [20]. The role of fingertip static coefficient of friction for a precise grip is another parameter along with the optical flow which was studied in previous paper. The authors have studied the contact forces decomposing them into normal and tangential components, and the variations of normal force with respect to tangential force. After studying the advantages and disadvantages of previous methods, the authors proposed a novel method based upon studying movements of a finger on the surface layer of a force and torque sensor having fixed axis. This allowed the estimation of coefficient of friction as a function of normal component of force during dexterous manipulation. The first session of experiments was performed for twelve subjects while six of them were subjected to another session after a week and no significant difference was noted in measurements. However, the researchers also faced limitations due to difference between static and dynamic frictional coefficients, moisture at the fingertip, etc. The results enable the prevention of object drop and further the estimation of safety margin by monitoring the static coefficient of friction [4]. An eletroadhesive method to control force of friction on fingertips to prevent sliding using haptics were also developed using Broadband electroadhesion [25]. An algorithm to render state-of-the-art frictional contact with maximum dissipation was demonstrated on several 6-DoF haptic examples [26]. In an attempt to rehabilitate amputees and physically handicapped, robotic hands were developed with sensory feedback to patient. The selected parameters were varied and sensors were used in output as decoders to assess the variability and the degree of extraction of information. The performance index of the decoders was then compared to that of humans and surprisingly the sensors outperformed humans in their experiments. Further, the design of delicate and sensitive tips of the fingers showed insights into touch mechanics and decoding algorithms [5].

IV. BRAIN MACHINE INTERFACES

Intracortical microstimulation (ICMS) was able to achieve natural-like control of Brain Machine Interfaces. Authors have used ICMS technique to perform artificial percepts. The authors through the experimental set up had tried to prove that artificial sensory feedback can be used to achieve this naturalistic control of brain. They examined how feedback & ICMS can be used for the control. The integration of the two into the sensorimotor system set up resembles the natural working of sensory motor neurons in an animal system. The future research may be on to learn higher degrees of freedom. To reach to its target, the subject, a monkey had been studied with purpose of minimized effort, trial time and smaller movements to achieve the distance coverage to reach the target. The visual feedback method based upon the behavioral performance metrics, which include delay in movement and estimation, to prepare for reaching the target when clubbed with mathematical methods gave the researchers insight into naturalistic learning of brain [6]. Ideas of machine learning were utilized in the data-driven haptic rendering for high-dimensional complex data [28]. In another paper, authors have tried to investigate the manipulation effects of varying mechanical inputs by studying them for a particular biomechanical disease/ problem. The researchers worked to control the motor outputs after necessary processing. The effect of haptic manipulation was studied on eleven participants. A haptic device was used for the required manipulation. The authors witnessed success in eliminating the symptoms of diseases and also the manipulation resulted in increased effectiveness of therapy. The results were statistically validated, thus a huge success in using haptics for reducing symptoms and increasing effectiveness of treatment [7]. Another very interesting research work was undertaken by authors to manipulate actions using two hands which act separately, which was somewhat awkward as very less is known about two hands working separately, which is considered cooperation in general. They classified the actions based upon to be done by dominant or the non-dominant hand. Two identical robotic devices applied on wrist of a subject showed that haptic feedback is necessary for completing a task in such a case. The task was tested on four separate conditions of no feedback, visual feedback, force feedback via haptic devices and both. The trajectories of end effectors measured at a particular frequency quantified similarities and differences between different task conditions and results. The authors could not find improved results for both feedback condition, it increased complexity though. Finally, they concluded that such feedback when driven by haptics lead to enhanced task performance and thus show great opportunities for applications in medical field [8]. Another admittance-type robotic manipulator was designed to control motion in response to user applied force. Upon varying some mechanical and electrical parameters, for microsurgery/ micromanipulation activities, the results indicated that gain scheduling results in improved performance. The paper emphasizes on proper structuring of tasks for robotic manipulation, which can be further controlled by user. Since microsurgery is very high precision task, admittance-type robotic devices may be used in a more stable manner. In this, the user directly interacts with a sensor on the robotic device, while the robot in turn is controlled by a computer, which makes the robot move in response to the force applied. The work contributes to previous studies by evaluating the performance under varying operation conditions. The study also considers the scaling factor and how it is affected by gain, velocity, etc. However, the results showed a general independence from scaling factor. Accuracy was poor for some operating conditions while some range of velocities exhibited maximum accuracy. Precision was insensitive to velocity as well as admittance. The paper concludes that the precision is poor at low velocities and higher admittance gains. An inverted relationship was observed between force & velocity. Ultimately, gain scheduling resulted in improved performance of system [9]. While evaluating the velocity estimation method, another paper compares the effects of passive and real-time estimation methods for velocity [24].The paper focuses on visuo-haptic matching, calculus errors, required adjustments and the benefits thereof. The technical paper shows, based upon experiments, improved results in reaching a target and reduced residual force ta the effector end. They showed that individualization of haptic guidance was more beneficial to telemedicine system than matching systems [10]. In another work, the authors proposed an interactive dynamic system for passing visual information via touch and hearing sense of blind. The main focus, however, was on passing information about the shape of an object. Tre representation of visual signals in such forms required an experimental set up where sound was used as a main source of information for localization of object and identification of shape of object, etc, while touch sense was used for feedback and pointing purpose. The authors also compared their results with the then existing techniques and other experimental set ups. It was concluded that combination of modalities had better results, like raised-dot pattern on objects and sound as well. The interface provided provision for augmentative studies using other devices. Hence, the interactive approach is open for lot of future work in telemedicine [11]. To improve such human-robot work performance in telemedicine, a scaling strategy based upon dynamic haptic force feedback was used for mobile robots [21]. A survey conducted on developmental robotics shows an overview, classification and vertical analysis of existing system, discusses the concept of affordance and tries to establish it as a promising research area. Keeping in view that robots should have human-like intelligence, each skill needs to be developed inside the system as a separate task. Basically, they say that robot has to be biologically inspired completely and have discussed various types of work in this direction. An important consideration in this is affordance, ie, how a machine learns about the environment and stores it for further use. The learning methods may be related to behavioral or perceptual capabilities. The paper discusses the affordance relationship and its associated characteristics which have been adapted from human behavior like potential to exist in environment to co-exist and have general application potential instead of specialized one. The authors have touched the Markov structure, 3-D environment, indirect human-robot interaction amongst modeling etc. An extensive work is thus deliberated by the researchers in the survey paper. General and algorithmic analysis have been done along with infant, developmental, motivated and life-long learning, like humans. The advantages of affordance which include planning, control, recognition, transferability and programmability have also been discussed [12]. Another survey based upon the work on haptics for social touch had been explored. The paper does distinctions amongst discriminative touch and affective touch, and discusses the effects of social touch and various factors affecting it. Another interesting area of research related to mediated social touch, ie, haptic technology for social communication from a distance has been discussed in another study. This included sensing and reproducing the touch, developing prototypes and some empirical studies. Simulated social touch has also been outlined, which is also based upon haptic feedback technology. Thus, an overview of research work from diverse domains of neuroscience and psychology have been dealt with reference to human touch. An important conclusion and recommendation by authors in general is to proceed with the top-down or bottom-up approaches to provide a realistic simulation. The required feedback may be from visual or auditory pathway or may be complex [14].

V. WERABLE HAPTIC DEVICES

In a paper, the authors have attempted to develop a glove which mimics the computer system of human hand. The wearable sensing glove is based on magnetic and inertial sensors. The cutaneous device was developed keeping in consideration the requirement of reduced magnetic interferences. The experiments conducted showed comparisons between the errors using the gloves with and without haptic feedback technology. The estimation error and accuracy calculations show haptic technology to be on a much positive side [15]. Another group experimented on another design which included wearable haptic system for fingers. Here, augmented reality (AR) techniques was used. Wearable haptic device could provide strong feeling of actual touch. This certainly is seen as light in the improved performance for doing tasks [17]. Claudio et al also worked on such a system [19]. Wearable devices based upon immersion virtual reality for training of children with some neural impairments were also tested [31].

A small device was used to display forces during MRI-guided investigations. Specific studies were carried out for detection of touch of a needle on to the silicone membrane. The membrane puncture was detected with very high success rate even with very light contact forces [29]. A novel interaction system used a safe and simple passive haptic stimuli by small bumps below the feet of the subject. The experiments revealed that the design of the shape of the bumps was important [30]. A standard bilateral and impedance control for haptic transmission by controlling the force, successfully reduced data and hence reduction in data traffic in communication [32].

VI. CONCLUSIONS

Basic principle of haptics is now not a new challenge for researchers. The task taken nowadays is to use and modify the concept to enhance its applicability and to increase the effectiveness for applications in all domains. Whereas haptics starts with touch and then there is the process to communicate with machine outside and brain inside the human body via these interface devices, which are based on different methods and techniques have given different, and sometimes, contradictory results. Every time the study starts with grasp, may go complex with sensing, vibration, motion, BMI, feedbacks, individually or along with other techniques, and so on. Haptic interface devices with feedback have certainly shown great comparative advantages for object detection and characterization. Other feedback methods along with haptic interfacing have also given applications in diagnosis and treatment of as complex as neurosensorial, motor-control or biomechanical diseases. The effects of variations in parameters like velocity of motion, gain, differing materials, scaling factors, feedback method, etc. have resulted in betterment of devices over subsequent time and research. The extensive studies carried out have a huge potential for practical applications of haptics in telemedicine and robotic surgery.

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