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Affective Haptics: Current Research and Future Directions

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***Abstract*—Touch plays a prominent role in communicating emotions and intensifying interpersonal communication. Affective Haptics is an emerging field, which focuses on the analysis, design, and evaluation of systems that can capture, process, or display emotions via the sense of touch. The objective of this paper is to present an overview of the recent achievements in affective haptics and to discuss how the sense of touch can elicit or influence human emotions. We first introduce a definition to the term "Affective Haptics" and describe its multidisciplinary nature – as a field that integrates ideas from affective computing, haptic technology, and user experience. Second, we provide a thorough discussion about the effectiveness of using the haptic channel to communicate affective information through direct and mediated means. Third, we present a variety of applications in the area ranging from inter-human social interaction systems to human robot interaction applications. Finally, we discuss some the key findings discerned from the various surveyed papers, and present some of the challenges and trends in this field. We extract the following conclusions pertaining to affective haptics: (1) Haptic stimulation can be successfully used to achieve a higher level of emotional immersion during media consumption or emotional Tele-presence, (2) existing research has demonstrated that haptics is effective in communicating valence and arousal, and the emotions of happiness, sadness, anger and fear, less focus has been given to the communication of disgust and surprise, (3) the haptic-based affect detection remains an understudied topic whereas haptic-based affect display is a well-established subject, and (4) the interpretation of haptic stimulation by human beings is highly contextual.**

***Index Terms*— Affective computing, Haptic interfaces, Human computer interaction, social computing, tactile sensors.**

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I. Introduction: From Affective Computing to Affective Haptics

SINCE the beginning of the 21st century, researchers have produced tremendous breakthroughs in information technology. However, to date, we have not crafted systems that can intelligently recognize our emotions or experience sentiments like we do. For more than a decade, researchers have been striving to develop systems that can detect, display, elicit and communicate affects. The study and development of these emotionally adept systems is called "Affective Computing"; an interdisciplinary field that combines ideas from psychology, cognitive science, and computer science [1].

We define affect detection as the ability of a computer to characterize aspects of the emotional status of its user. Affect display pertains to the emulation of emotions by a computer through the modulation of information presented to the user such as text mood, speech temperament, facial or gestural expressions of an avatar, among other methods. Similarly, affect elicitation is the generation of stimuli by a computer in the goal of evoking a user emotion. Finally, affect communication refers to the transmission of affective information from one entity to another (directly or through a technological medium). An entity in this context refers to either a human or computer.

A recent research trend has emerged in the field of affective computing that explores the possibility of employing haptic technology in the process of detecting, displaying and communicating affects. Hence, in the following sub-sections, we will define the term haptic technology, explore the advantages of integrating the sense of touch with affective computing systems and finally introduce the topic of affective haptics as the main focus of this paper.

A. Haptic Technology

Haptics, a term that was derived from the Greek verb "haptesthai" meaning "to touch", refers to the science of sensing and manipulating through touch [2]. This word was introduced at the beginning of the twentieth century by researchers in the field of experimental psychology to refer to the active touch of real objects by humans. In the late eighties, the term was redefined to enlarge its scope to include all aspects of machine touch and human-machine touch interaction. Currently, the term has brought together many disciplines including biomechanics, psychology, neurophysiology, engineering, and computer science to refer

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to the study of human touch and force feedback as a modern human computer interaction paradigm.

Early research on haptic stimulation has focused on applications aiding blind or visually impaired people [3], but later developments included a wide spectrum of applications including entertainment and gaming [4], mobile and touchscreen interaction [5], emotional [6] and interpersonal [7] communication, health care (such as physical rehabilitation and Tele-surgery) [8], Tele-robotics and Tele-operation [9], education and training [10], and e-commerce [11].

With the emergence of haptic technologies and increasing interest in affective computing, researchers may rely on the use of haptics to display emotion to users and also to detect their emotions to communicate what audio-visual modalities cannot accommodate [12].

A haptic device is a mechanical apparatus that is used to exchange forces between a computer and a user. It is typically classified as force feedback (kinesthetic) or tactile [2]. Kinesthetic devices display forces or motions through robotic interfaces. They are used mainly to communicate relatively large forces to emulate weight or collision forces in a virtual environment [2]. Tactile haptic devices stimulate the skin in order to simulate objects' texture. This is typically achieved through the generation of vibrations [2].

B. Touch and Affective Computing

The strong interest in affective computing is driven by a wide spectrum of promising applications in many areas such as virtual reality, smart surveillance, natural interfaces, enhanced human-robot interaction, gaming and entertainment, online social interaction, etc. [1]. Most existing affective communication techniques use text, speech, gesture and facial expressions information transfer or a combination of these approaches, known as multimodal methods. These techniques exploit only two of the human senses: visual and auditory [13]. Therefore, the next critical step is to bring the sense of touch to computer-mediated emotional communication.

Despite the pivotal role of touch in a variety of human communication, research has paid very little attention to how touch is utilized to communicate affection [14]. The sense of touch provides a very powerful method of eliciting and modulating human emotion. We use touch to share our feelings with others, and enhance the meaning of other forms of visual or verbal communication. Human emotions can be easily evoked by different cues, and the sense of touch is one of the most emotionally charged channels [15].

C. Affective Haptics

Affective haptics is a novel interdisciplinary area of research, which focuses on the design of devices and systems that can detect, process, or display the emotional state of the human by means of the sense of touch. Affective haptics comprises three complementary communication channels, namely tactile, thermal, and kinesthetic.

We define affective haptics as the research area that involves "the acquisition of human emotions through the human touch sensory system, the processing of emotion-related haptic data to detect affect, and the display of emotional reactions via haptic interfaces. Emotions may be solely communicated through the sense of touch or coordinated/integrated with other sensory displays (such as audition or vision) in a multimedia system".

Affective haptics comprises three subdomains: affective computing, haptic interfaces, and user experience. Affective computing investigates methods to detect, display, elicit and communicate emotions [16]. Haptic interfaces provide a bidirectional communication of touch sensation with a human subject [2]. Finally, user experience examines how incorporating the haptic modality would enhance emotional immersion and the overall quality of user experience.

It is worth highlighting that affective haptics refer to the computational aspects of mediated affective touch. We will refer to solely psychological (human-human) research as "Affective touch". Affective touch studies how participants emotionally react to haptic stimuli and explores the quality of experience measuring methods. For instance, physiological reactions such as heart rate, facial expressions, electro-dermal activity, gesture expressions, or brain activities can be gaged. Some studies have also used subjective measures such as rating personal emotional experiences with various scales. For instance, the PAD 3D affective space [17] is frequently used to analyze emotion related continuous ratings of subjective experiences. It features three bipolar dimensions of valence/pleasure (unpleasant-pleasant), arousal (not arousing-arousing) and dominance (feeling in control-being controlled). Several other subjective affect measurement scales exist, such as the Positive and Negative Affect Schedule (PANAS) [18] and the State-Trait Emotion Measure (STEM) [19]. A discussion of these scales is beyond the scope of this paper.

Affective haptics has several applications. For instance, in e-learning applications, affective tactile stimulation can be applied to reinvigorate the learner's interest when she or he is bored, frustrated, or angry [20]. Psychological health applications may benefit from affective haptics by determining a patient emotional state using the sense of touch [17]. A growing area in emotional communication focuses on the use of robots for personal assistance, where a companion robot (such as digital pets [21]) uses affective haptics to enhance realism and provide a higher quality of human-like interaction. Other applications include the following: health care (such as treating depression and anxiety [22] or assistive technology and augmentative communication systems for children with autism [23]), affective and collaborative entertainment and gaming [24], online communication [25], social and inter-personal communication [26], and psychological testing [27]. That is probably the reason for the exponential rise in the interest in affective haptics in the last decade (see Figure 1).

D. Paper Organization

The rest of this paper is organized as follows: Section 2 gives an overview of the literature pertaining to affect

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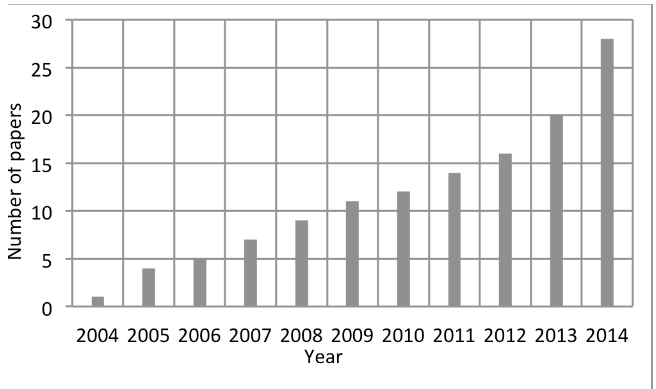

Fig. 1. The chart reports the number of papers per year with the word "Haptics", "Tactile", "Touch", or "vibration" and "emotions", "affective", "user experience" in their title (sum over IEEE Xplore and ACM Digital Library).

communication via direct human-human touch. Section 3 describes the concept of remote affect communication using haptic technology and surveys related works. Section 4 describes some of the most important affective haptics applications proposed by researchers in the domain. Section 5 details the challenges and trends in affective haptics; it also summarizes some of the consistent findings that we have observed across several studies. Section 6 presents our concluding remarks and a brief outlook into future works.

II. Affect Communication with Direct Touch

Affect communication with direct touch involves studies where human subjects use a body part (such as the hand) to apply a direct haptic stimulus onto another subject's body in the goal of communicating emotions. This area of research is underdeveloped probably due to two factors. First, despite its great social importance, touch has received little attention in the field of affective science since it was believed to merely amplify the intensity of emotional displays from audio-visual cues [28]. Second, the topic requires a concerted multidisciplinary effort to be investigated and hence suffers from the common difficulties associated with multidisciplinary research.

Early studies on haptics as an affective modality claimed that direct haptic affect communication is limited to valence (positive versus negative emotions) and emotion intensity [29]. Results showed that most touch behaviors have symbolic content, and are capable of communicating emotions. Touch codes a wide range of ambiguity for emotion communication and thus contextual factors are critical to the interpretation of affective touch.

The authors in [30] tested the hypothesis whether users can recognize the six universal expressions of emotion (anger, disgust, fear, happiness, sadness, and surprise) by touching a live face, through static and dynamic expressions. Experiments showed that users overall mean accuracy for static facial expressions of emotions was 51% and 74% for the dynamic facial expressions of emotions. Results also confirmed that happiness, sadness, and surprise were all highly recognizable, while anger, disgust, and fear were less so.

More recently, studies by Hertenstein et al. [28][31] exploring haptic-based communication of emotion discovered that people could identify anger, disgust, fear, gratitude, happiness, love, sadness and sympathy from the experience of being touched on either the arm or body by a stranger, without seeing the touch. In the first study [31], two subjects (an encoder and a decoder) participated in the experiment where the encoder is given twelve emotions in a randomized order and is asked to touch the decoder's bare arm to signal each emotion. The decoders could detect anger, fear, disgust, love, gratitude, and sympathy via touch with accuracy rates ranging from 48% to 83%. The study showed that strangers were unable to communicate the self-focused emotions embarrassment, envy and pride, or the universal emotion surprise. The subsequent study [28] showed that happiness and sadness could be decoded with recognition rates higher than chance level.

In a later study that re-examined data collected by Hertenstein et al. [28], Keltner et al. [30] found some interesting patterns of gendered communication. Their results showed that anger was communicated well above the chance rate only when the dyad consisted of males. Happiness was communicated only when the dyads consisted solely of females. Interestingly, sympathy was communicated well above the chance rate only when there was at least one female in the dyad. Finally, the decoder could recognize the gender of the encoder with a recognition rate of 70% to 96% (depending on the specific gender-dyad composition).

Moreover, Coan et al. [33] confirmed that the interpretation of emotions is significantly influenced by the person giving and the person receiving the touch. A subsequent study by Thompson and Hampton [334] compared the ability of romantic couples and strangers to communicate emotions solely via touch. Results showed that both strangers and romantic couples were able to communicate universal and pro-social emotions, whereas only romantic couples were able to communicate the self-focused emotions envy and pride. The study also showed that people were more likely to confuse particular emotions if these emotions matched along the arousal/valence plot (for example envy, anger and disgust with high arousal and negative valence).

Direct touch affect communication is contextual; studies found that haptic behavior alone is not adequate to identify distinct emotions [29]. In an interesting study, 23 different types of tactile behavior (hugging, squeezing, shaking, etc.) were identified [28]. Results concluded that the tactile behavior alone was not adequate to identify distinct emotions. For example, stroking was observed when communicating sadness but also when communicating love or sympathy. Furthermore, it was found that other than the choice of tactile behavior, the duration and intensity of the stimulus has to be modulated for improved discrimination between emotions.

A study to measure the physical properties of affective touch is presented in [35]. A wearable sleeve consisting of a pressure sensitive input layer is used to record a number of expressions of discrete emotions. Results revealed that to express fear, happiness, and anger, participants touched a

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significantly larger surface area than for the expression of gratitude, sympathy, and sadness. Furthermore, most emotions were expressed with relatively equal intensity. However, for sympathy, participants used significantly more force when compared to fear, anger, and gratitude. As for the duration between touches, anger had significantly shorter gap duration than happiness and love. Disgust had a significantly shorter duration than fear, happiness, sadness and love.

Given that human beings can detect emotions through the sense of touch, it is conceivable that computerized sensors can achieve the same results. This would enable computers to detect the affective state of users that are haptically interacting with them.

Table 1 shows a summary of affect communication with direct touch literature.

III. Affect Communication with Mediated Touch

Affective communication with mediated touch involves the use of an interface to convey the haptic sensation from one user to another (typically using a haptic device or a tactile screen) or from a machine to a user. We categorize mediated touch technologies based on the haptic device used to realize these systems: force feedback (kinesthetic) and tactile mediated touch. In the next sub-sections, we will explore these categories and present the evidence supporting the employment of these technologies for affect communication.

A. Affect Communication with Mediated Force Feedback Touch

The haptics research community has considered force feedback mediated affective communication in a limited way. Some of the first works in this realm investigated whether affect can be communicated through a haptic medium. To that end, Smith and MacLean [15] studied the issue while attempting to isolate considerations pertaining to the kinesthetic haptic device type. Hence, they considered a design space for mediated interpersonal haptic interaction composed of three sub-spaces: the type of human interaction, the haptic device and the virtual mediating model. The main conclusion they reached through their experimental results is that affect can be communicated over a purely haptic link.

Similarly, Bailenson et al. [26] examined the phenomenon of encoding emotional information through a haptic channel. In particular, they focused on the exchange of basic emotions of anger, disgust, joy, fear, interest, sadness, and surprise via mediated touch. However, in their experiments, subjects did not enter into direct haptic mediated communication. In a first experimental stage, a group of subjects were asked to convey the basic emotions by manipulating a 2 DOF haptic device. The device manipulations were recorded. In the second stage, another group of subjects were asked to hold the device while the recorded manipulations by the first group were played. They were then asked to specify the emotions they felt. The result of this work indicated that humans recognize emotions via haptic modality at a rate significantly above chance (33%) but not as accurate as people expressing emotions through non-mediated handshake.

Gatti et al. [36] focused particularly on the effect of simulated friction on arousal and valence. They conducted an experiment involving 36 subjects where they compared two scenarios: 1) presence of a simulated viscous force field and 2) absence of the force field when a subject manipulates a Phantom device. Results revealed a significant difference in self-reported arousal associated with haptic friction.

Instead of using the haptic link as the sole medium for mediated affect exchange, Bonnet et al. [37] studied how to combine haptic stimuli and visual expressions displayed by avatar in order to improve the display of emotions by computers. Results found that some emotions, like anger and disgust, are better communicated by adding haptic feedback to the visual display.

B. Affect Communication with Mediated Tactile Touch

Our literature study shows that most of the research in haptic-based affect communication focuses on the use of tactile interfaces. An early study on the relationship between emotion elicitation and tactile touch showed that tactile stimuli can be associated with qualitative adjectives such as “sweet”, “relaxed”, or “valuable” [38].

Typically, tactile interfaces used for affective communication are manifested as tangible objects or robots, wearable items or contactless devices (i.e. mid-air stimulation devices).

Few researchers have utilized robotic interfaces to communicate emotions. With an ultimate goal of creating therapeutic device, Yohanan and MacLean [21] developed the Haptic Creature device, a furry lap-sized social robot that perceives the world through touch, and expresses itself through ear stiffness modulations, breathing rate, and purring patterns. Experiments showed that the combination of different tactile stimulation techniques allows the perception of some categories of positive emotions. This result motivated the development of a furry artificial lap-pet to sense human emotion through touch [39]. In a subsequent work, the Creature design was integrated with a piezoresistive fabric location/pressure sensor [40]. Nine (9) key affective touch gestures were used in the usability study. 94% recognition rate could be achieved when the system is trained on individuals whereas 86% when applied to a random set of participants. The system could also recognize which participant is touching the prototype with 79% accuracy. A similar idea is presented in [41] where a human/poultry interaction is made possible using a doll resembling the remote bird and a tactile suit that is put on the animal’s body. A usability study showed that this human-poultry communication system promotes pleasure in both humans and poultry.

Wearable technology with haptic features can introduce new avenues for communicating emotions. An early work in this direction was the TapTap prototype, which is a wearable haptic interface that can record and playback patterns of touch in order to experience the affective human touch [42]. A subsequent effort at Philips Research Europe demonstrated

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Table 1: Summary of affect communication with direct touch literature

Reference	Touched Part	Touching Part	Emotions Rendered	Results/Comments
[29]	The whole body	Hands	Valence discrimination: positive versus negative emotions	Most touch behaviors have symbolic content, and are capable of communicating emotions. Touch codes a wide range of ambiguity for emotion communication. Contextual factors are critical to the meaning of affective touch.
[30]	Live human face	Hands	Six emotions: anger, disgust, fear, happiness, surprise, and sadness.	Recognition rate well above the chance rate (33%). Direct handshake gave better recognition rate than haptic device mediated handshake.
[28], [31]	Forearm	Hands	Six emotions: anger, fear, disgust, love, gratitude, and sympathy.	Recognition rate 48% to 83%. Strangers unable to communicate self-focused emotions embarrassment, envy and pride, or the universal emotion surprise. Happiness and sadness could be decoded with recognition rates well above the chance level
[32]	Forearm	Hands	Six emotions: anger, fear, disgust, love, gratitude, and sympathy.	Anger communicated well above the chance rate when dyad consisted of males (62%). Happiness was communicated only when dyad consisted solely of female. Sympathy communicated well above the chance rate when at least one female in the dyad (62%).
[33], [34]	Forearm	Hands	Six emotions: anger, fear, disgust, love, gratitude, and sympathy.	Strangers and couples communicate universal and pro-social emotions. Only couples communicate self-focused emotions (envy and pride). Strangers and couples confused emotions closely located along the arousal/valence plot.
[35]	Forearm	Hands	Eight emotions: anger, fear, sadness, happiness, love, disgust, gratitude, and sympathy.	Fear, happiness, and anger, have larger touched surface area than gratitude, sympathy, and sadness. Most emotions were expressed with relatively equal intensity. Anger had shorter gap duration than happiness and love. Disgust had shorter duration than fear, happiness, sadness and love.

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haptic jacket that focuses on influencing the emotions of movie watchers [43]. The jacket contains 64 tactile stimulators to render emotional effects to the user's skin. Results showed that emotions are accompanied by different physical reactions, and that by stimulating these physical reactions using the jacket, the accompanied emotions could be evoked. Cha et al. [44] implemented HugMe, a synchronous haptic teleconferencing system to express intimacy remotely. Using a 3-DOF force feedback device, the user can touch a remote user who, in turn, can feel the touch on the contacted skin through a wearable jacket. This jacket contains an array of vibrotactile actuators that activate depending on the locations of the touches. In a subsequent study, a temperature actuator and a heartbeat sensor were integrated into the tactile jacket to facilitate the display of the six universal emotions: love, joy, surprise, anger, sadness, and fear [45]. Results showed that the overall quality of user immersion is enhanced when the haptic jacket is used while watching a movie. Finger-stroke features (such as number of strokes, stroke length, stroke speed and stroke pressure) during gameplay on an iPod were extracted and analyzed using machine learning algorithms to automatically discriminate four emotional states (excited, relaxed, frustrated, bored) [46]. Results show that arousal can be detected with a recognition rate of around 88% whereas valence is detected with around 85%. The discrimination of the four emotions were also well above the chance level; ranging from 69% to 77%. Krishna et al. developed a haptic glove (named VibroGlove) to deliver facial expressions of an interacting partner to people who are blind or visually impaired [47]. Vibrotactile motors, mounted on the back of a glove, provide a means for conveying haptic emoticons that represent the six basic human emotions and the neutral expression of the user's interaction partner. Results showed a great potential for enriching social communication for people with visual impairments.

Researchers have also explored emotions mediated through mid-air tactile stimulation [48][49]. Mid-air tactile stimulation seeks transmitting tactile stimulus through air without any physical contact between the haptic device and the human body. Existing technologies to provide mid-air tactile stimulation include air jet that varies air pressure to transmit air pulses [50], ultrasound radiation force that occurs when ultrasound is focused on the human skin [51], and laser [52]. Hashimoto and Kajimoto [48] conducted an initial study projecting emotional information through tactile sensations on the palm using air pressure. In a subsequent work, Obrist et al. explored the communication of emotions through a haptic system that uses tactile stimulation in mid-air [49]. Haptic descriptions for specific emotions (happiness, sadness, excitement, fear) were created by one group of users and validated by another group. Results showed that participants were able to express and recognize tactile stimulation to convey emotional meanings (valence and arousal). The authors in [53] proposed a new tactile stimulation strategy for the communication of emotions via mobile air jet, which provides a non-intrusive tactile stimulation on different and large areas on the human body. Results revealed that participants evaluated low flow rate stimuli as pleasant, and high flow rate stimuli as being n and dominant.

Whereas several studies clearly confirm that to can give a good measure of emotion, most of have been carried in acted situations, and it is these findings would vary in a realistic context. Salminen et al. [54] showed that emotional rat stimuli is affected by the environmental conte experiment is conducted. Hence, a better underst contextual effects of haptic affective perception i

A summary of the mediated haptic affective co techniques is shown in Table 2 where we common characteristics described in all refere haptic interface, body part onto which the haptic applied, affect communicated and stimulus pa also reserve a column to summarize the mo finding(s) of each study. Furthermore, Table regardless of the haptic interface use or stimulu haptic information can be used to communic information effectively.

IV. Applications of Affective Hap

Numerous affective computing applications haptic modality for communication of emotio proposed. In this section, we identify majo applications that have received attention in affective haptics. Namely, we focus on affe concepts applied to social interaction, healthcare entertainment, and human robotic interaction.

A. *Affective Haptics for Social Interaction*

Nonverbal information plays a crucial role in h social interaction [55]. Most studies that nonverbal emotional cues in interpersonal co focused on facial expressions [56]. Accordi researchers, "touch" not only plays an important interaction but is also a fundamental human general, social touch contributes to affective co in two forms. First, touch can communicate the of emotion [58]; it communicates either pos through warmth and intimacy or negative valen discomfort. Second, touch is thought to emotional information received through other m as audio or visual [29].

Several research studies investigated how intensify emotional information received th modalities. Rovers and van Essen [59][60] hav use of hapticons (vibrotactile patterns) in insta systems to boost affective information. Howev stimuli employed were based on the intuition and thus lack a systematic validity of th communicative qualities associated with them. C proposed a new method for conveying emotiona using haptic technology to overcome the lack of online negotiation. Online negotiators play a ga

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Table 2: Summary of affect communication with mediated touch literature

Reference	Haptic Interface	Body Part	Affects (or Affective Components) Communicated	Stimulus Parameters	Results/Comments
[26]	Force Feedback: 2000 force feedback joystick from Immersion	Hands	Seven emotions: anger, disgust, fear, interest, surprise, sadness, and joy.	Movement duration, speed, acceleration, angle, and position.	Recognition rate 51% for static detection and 74% for dynamic detection. Happiness, sadness, surprise highly recognizable; anger, disgust, and fear less so.
[37]	Falcon haptic device from Novint	Hands	Joy, Surprise, Pride, Envy, Fear, Love, Disgust, Disregard, Embarrassment, Sadness, Gratitude, Interest, Fascination, Anger	Movement duration, distance, velocity and amplitudes on X, Y and Z.	System depicts an avatar displaying emotions. Results show that emotion classification by the user increase with the addition of haptic information.
[36]	PHANToM device from Sensable (now Geomagic)	Hands	Arousal, Valence	Device movement friction force	Self-reported level of arousal while viewing pictures increased when haptic effect was applied.
[21], [39], [40], [41]	Tactile: Pet-like Robot	Hands	Arousal, Valence	Ears stiffness, breathing rate, vibrotactile purr.	Human-pet interaction promotes pleasure. Stiffness proportional to arousal, Faster breathing associated with higher arousal, Asymmetric breathing and purring associated with positive valence.
[46]	Tactile: Touchscreen iPad	Finger tip	Four emotions: excited, relaxed, frustrated, and bored.	Finger-stroke behavior: contact coordinates, contact area, and contact duration.	Recognition rate 69% to 77%. 89% discriminated two levels of arousal and two levels of valence.
[42], [43], [44], [45]	Tactile: Vibrotactile Jacket	Torso and arms	Love, enjoyment, fear, sadness, anger, anxiety, happiness.	Vibration intensity, vibration duration, vibration speed.	Higher intensity/speed indicated surprise or happiness, Continuous stimulation associated with love, High intensity down the spine for fear and anxiety
[15]	Force Feedback: Haptic knob	Hand	Angry, delighted, relaxed, unhappy.	Force magnitude, Speed of ball, color of ball.	Kinesthetic feedback brings beneficial effects to expression of emotions. What emotion most well recognized is not known.
[53]	Tactile: Mobile Air Jet	Forearm	Valence, Arousal, Dominance	Flow rate, movement velocity	Higher flow rate associated with more arousal and more dominance, Low flow rate are more pleasant, Slow movements are more pleasant than static stimulation or fast movements.
[47]	Tactile: Vibrotactile Gloves	Hand	Happiness, sadness, surprise, anger, fear, disgust.	Haptic expression icons	Happy is represented by a U shaped pattern, sad by an inverted U, surprise by a circle, neutral by a straight line, anger by open mouth icon, fear by quick successive vibration sequences at fingertip, disgust by slightly opened mouth icon.
[48], [49]	Tactile: Acoustic radiation pressure system	Palm	Valence and arousal	Frequency, intensity, duration.	Participants were able to express and recognize tactile stimulation to convey emotional meanings (valence and arousal) using mid-air haptic interface.
[38]	Tactile: Rotating Cylinder	Finger tip	Pleasantness, approachability, arousal, dominance	Cylinder rotation direction, burst	Simple haptic stimuli (rotating cylinder touched by fingertip) can carry emotional information.

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Phantom Omni device where they "throw" a white ball after making a statement. As the other user catches the white ball, the force feedback can be felt on the Phantom device – ball only moves in x-direction (back and forth between the negotiating parties). Their experimental study has shown a significant improvement in the sense of presence when haptic interaction was enabled.

Several social affect communication projects have focused on strengthening parent-child relationships. A Tele-haptic body touching system that enables parent/child haptic interaction is described in [61]. The study presented an "Internet pajama" to promote physical closeness between a remote parent and a child. The pajama captures the forces generated by a hug applied by the parent to a doll or teddy bear and transfers it to the child. Researchers at the MCRLab of the University of Ottawa introduced the HugMe system as a synchronous haptic teleconferencing system aimed to express intimacy remotely [44][62]. Using a force feedback device (Novint Falcon), the user can touch a remote user who, in turn, can feel the touch in the contacted skin through a wearable haptic jacket. The jacket contains an array of vibro-tactile actuators controlled by a remote application via Bluetooth. An enhanced prototype of the haptic jacket is presented in [63] to add neck warmth, heartbeat simulation, and neck vibrations. A similar haptic jacket equipped with 64 tactile simulators was also developed in the Philips Research Europe [43]. Tsetserukou et al. [64] propose a system called iFeel_IM! to enhance the emotionally immersive experience of communication in second life by reinforcing human feelings using a wearable affective haptic device called the HaptiHug device. Three groups of haptic gadgets are built. The first is intended for emotion elicitation implicitly (HaptiHeart, HaptiButterfly, HaptiTemper, and HaptiShiver), the second evokes affect in a direct way (HaptiTickler), and the third uses the sense of social touch (HaptiHug) for influencing the mood and providing a sense of physical co-presence [65]. Tsetserukou1 and Neviarouskaya extended the iFeel_IM! system to support emotional telepresence where user can not only exchange text messages but also emotionally and physically feel the presence of the communicating partner [66].

As opposed to appending haptic stimuli to textual or graphical interaction, some researchers focused on the communication of affect over a purely haptic link. Many of these works explored the haptic emotional exchange between romantic partners and strangers. For instance, Smith and MacLean [15] used a haptic turning knob to study the communication of four distinct emotions between dyads. The interactions were designed to simulate communication at different levels of intimacy. The study involved 32 participants, half of whom were strangers and the other half were romantic couples. It was found that the dyads in a romantic relationship performed significantly better in identifying the haptically presented emotions compared to the stranger dyads. Park et al. [67] showed that sharing a tactile vocabulary enabled couples to express and understand emotions over distance. For positive emotions participants used weak touches, while negative emotions were often expressed through hard, fast, and continuous touches. Similarly, Mullenbach et al. [68] used a variable friction surface of the TPad Tablet to enable affective communication between pairs of users. Three haptic applications were implemented: text messaging, image sharing, and virtual touch. The applications were evaluated with 24 users, including romantic couples and strangers. Results showed that users readily associated haptic interaction with emotional expressions and that the intimacy of touch in the contexts they studied was best for communication with close social partners. Samani et al. [69] presented a system (named XOXO) that facilitates remote intimate interaction by communicating hugging and kissing sensations between dyads.

Huisman and Frederiks [35] present a wearable tactile sleeve equipped with vibration motors that can convey six different emotions. They identified different types of touch for each emotion (e.g., stroking for love, squeezing for fear), but also reported participants' difficulty in differentiating the intensity of the expressions on the worn sleeve. These results suggest the potential for communicating emotions through touch but do not inform sufficiently which or how specific emotions can be mediated through haptic feedback.

As opposed to inter-human social communication, Bickmore et al. [70] designed a computer simulated agent for human-computer affective social interaction. The agent models human conversational touch in synchrony with speech and facial expressions to convey empathy to users in distress. Touch is communicated by an air bladder that squeezes the user's hand. Their experimental results showed that when touch is used alone, the hand squeeze pressure and number of squeezes parameters are associated with users' perception of the agent's arousal level. Moreover, parameters such as the number of squeezes and squeeze duration are associated with subjects' perception of the agent's valence.

Even though affective haptics in social interaction has gone a long way towards creating a human-like experience, several issues remain prominent. First of all, sensory suite that adequately captures social touch parameters (such as sheer and tangential forces, compliance, temperature, skin stretch, etc.) are lacking. Only after collecting sufficient information about social touch would it be possible to apply algorithms that determine accurate appraisal of the touch (a preliminary effort in this direction can be found here [71]). Secondly, the congruency of touch in space, time and semantics remain a major challenge. Haptic cues must be displayed in complete synchronization with other (mediated) display modalities (visual, auditory, olfactory, etc.) in order to communicate meaningful social touch. Thirdly, the effects of physical properties of haptic cues are not well understood. Future research should focus on how the quality of affective haptic display can be enhanced by controlling specific haptic parameters (for instance amplifying or attenuating temperature or force profiles) or by the addition of other communication channels. Finally, other important challenges relate to how to haptically render valence and arousal, how touch etiquette for social interaction should be, which multisensory interactions are relevant, and how to incorporate social, cultural and individual differences with respect to acceptance and meaning of affective touch.

B. Affective Haptics for Healthcare

Affective touch is a crucial part of human development and well-being, especially for the young, elderly, and ill. A system capable of providing affective haptic communication can enable many valuable applications in therapy, rehabilitation, treatment of cognitive disorders, and the assistance of people with special needs [40]. Research has demonstrated that touch triggers a cascade of chemical responses, including a decrease in urinary stress hormones (cortisol, catecholamine, norepinephrine, epinephrine), and increased serotonin and dopamine levels [72]. The shift on these bio-chemicals has been proven to decrease depression [73].

Affective haptics presents a great potential in aiding with the treatment of various ailments. Early studies have shown that touching a loved one can dramatically reduce stress during medical procedures [74]. Indeed, a number of psychological disorders, including depression, hyperactivity, autism, and Alzheimer's, can benefit from touch therapy provided by a haptic interface. For instance, a recent study has reported that the application of touch can be soothing and help counteract the effects of experienced violence and depression by children, adults and the elderly [17]. Another interesting study showed that robotic companions that display an emotional response through haptic (vibration pattern, temperature, etc.), voice and gestural output can render a positive therapeutic effect on patients and help them feel less lonely [75].

The authors in [22] developed three prototypes, namely Touch Me, Squeeze Me, and Hurt Me with vibrotactile, pneumatic and heat pump actuation to convey emotions to individuals with autism using touch. The prototypes are capable of reproducing several affectionate touch- pressure, directional stroke, percussion, and heat. A pilot study with the prototypes revealed the importance of customizing the haptic actuators (intensity, location, patterns) for each individual. They also concluded that men and women reacted differently to two types of actuation: women preferred the gentle vibrating motors and disliked the more violent solenoids, whereas men preferred the otherwise. Another research work presented a tactile gamepad capable of conveying emotion for autistic individuals via tactile stimulation [23]. A preliminary study with 9 children with autism showed that tactile stimulation is useful for the enhancement of emotional competences of children with autism and to help reduce stereotypical behaviors.

In spite of the numerous therapeutic approaches, theories and practices that systematically and effectively use touch in health care (such as psychotherapy), affective haptics has not received deserved attention due to the "taboo" effect that often sexualizes and even criminalizes touch [76]. This could exactly be an opportunity since mediated touch tends to be less sexualizing or infantilizing the meaning of touch. Another interesting open question about the deployment of affective haptics in health care is the development of a code of ethics for mediated touch.

Individuals with visual impairment have limited ability to interact with their sighted peers due to an inaccessible visual channel through which most communication cues are conveyed. Such situations may lead to social avoidance and isolation, and prevent individuals with visual impairment from fully participating in society. Most existing work in this area has focused primarily on displaying facial expressions.

Early work by Liu and Li proposed mapping the manifold of facial expressions to the back of a chair for vibrotactile stimulation [77]. To compute the manifold of facial expressions, they proposed an extended locally linear embedding (LLE) algorithm for analyzing the emotional content of videos of facial expressions in real-time. The vibrotactile display is capable of representing happy, sad and surprise where the stimulation is arranged into three axes (one for each emotion). The intensity of the emotion is also represented by the intensity of vibration along the three axes.

Krishna et al. developed a haptic glove (named VibroGlove) as an assistive aid to for people who are blind or visually impaired to visualize facial expressions of other humans [47]. The six universal emotions were represented and tested with various vibrotactile patterns (for instance, happiness is represented by a U shaped pattern whereas sadness is displayed as an inverted U, etc.). Results showed a great potential for enriching social communication for people with visual impairments. A similar work is presented in [78] where a haptic chair is developed for presenting facial expression information to people who are blind. A chair was equipped with vibrotactile actuators on its back, forming an inverted Y. A camera tracks the mouth of an interaction partner and vibrates along any one of the three axis of the Y, based on whether the interaction partner was neutral, happy, sad or surprised.

A subsequent study tested whether congenitally blind subjects can understand 3D raised-line pictures of facial expressions of emotions, and if so, whether they can integrate information serially gathered from tactile pictures of emotional faces into a holistic representation [79]. Results suggested that raised-line pictures of emotional faces are intelligible to individuals with visual impairment. Krishna et al. developed a haptic glove (named VibroGlove) to deliver facial expressions of an interacting partner to people who are blind or visually impaired [47]. The six universal emotions were represented and tested with various vibrotactile patterns (for instance, happiness is represented by a U shaped pattern whereas sadness is displayed as an inverted U, etc.). Results showed a great potential for enriching social communication for people with visual impairments.

A recent work by Yasmin et al. [80] introduced a system that integrates feature extraction with haptic recognition. They developed a dynamic haptic environment where a blind individual can perceive the reflection of his own facial expressions. The evaluation of this work was limited to sighted subjects. A similar work by McDaniel et al. [81] has

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also explored the use of affective haptics for communicating facial-expressions emotions for individuals who are blind. The authors introduced a haptic device, called the Haptic Face Display (HFD), consisting of two-dimensional array of vibration motors capable of displaying rich spatiotemporal vibration patterns presented through passive or active interaction. The users' emotional responses to vibrotactile patterns when the HFD device is embedded on the back of a chair (passive) were investigated. Results showed that pattern shape and duration influence emotional response for persons with visual impairment.

Existing studies show that the design of affective haptics for the visually impaired is still an open field where much needs to be done. One particular area where little is known is wearable haptic interfaces (more force-feedback interfaces than tactile interfaces) to enable pervasive haptic interactions. Another challenge involves giving users relevant information at the right time, and finding the means to best visualize it through haptic display.

C. *Affective Haptics for Gaming and Entertainment*

The literature includes two classes of affective haptics for gaming and entertainment research, namely gaming/entertainment for affective haptics and affective haptics for gaming/entertainment. Gaming/entertainment for affective haptics pertain to utilizing gaming and entertainment to induce spontaneous behaviors, which lead to transparent measurement of emotions. For instance, games engage participants in a way that is conducive for the expression of affection [82]. Moreover, this engagement can lead participants to partly forget about the experimental setting and thus induce spontaneous behaviors. Affective haptics for gaming/entertainment involves utilizing the haptic modality to enhance interactivity and immersion in gaming and entertainment by augmenting the existing audio-visual contents with physical interactions.

A few researchers utilized gaming and entertainment to support affective haptic communication. In [83] the authors presented a haptic-enabled version of the Second Life Client [84]. They modified the Second Life Client with two input modes explicitly designed for exploiting the force feedback capabilities of haptic devices to allow blind people to experience Second Life world for social communication. A similar work was introduced in [85] to facilitate emotional feedback such as encouraging pat and comforting hug to the participating users through real-world haptic simulation. A prototype haptic jacket system was developed to provide vibrotactile stimulation at the upper body of the user. In a subsequent work, Grace introduced Big Huggin' game that is played with a 30 inch custom teddy bear controller [86]. Players complete the game by providing several well-timed hugs to help a virtual avatar through obstacles – the hug stands as metaphor for providing support, courage, and inspiration. Gao et el. explored the use of touch behavior to capture a player's emotional state in a naturalistic setting of touch-based computer games [46]. Finger-stroke features (such as number of strokes, stroke length, stroke speed and stroke pressure) during gameplay on an iPod were extracted and analyzed using machine learning algorithms to automatically discriminate four emotional states (excited, relaxed, frustrated, bored). Results demonstrated an arousal detection rate of 88% and valence detection rate of 85%. Furthermore, the discrimination of the four emotions were all well above the chance level, ranging from 69% to 77%.

Researchers have also investigated the use of affective haptics for gaming and entertainment. Basori et al. [83] presented a feasibility study of how human haptic emotion can be applied in virtual reality game to enhance interactivity and immersive-ness. The human emotion is captured by a haptic device and sent to the game engine in order to control interactions with virtual characters. Emotions are classified into several different magnitude frequencies that are generated from the haptic device and give the user feedback about the virtual character emotion during playtime. A mapping approach to classify intensity of vibration into particular emotion appearance for a virtual reality game is presented in [87]. Happiness is expressed as low to medium vibration with short and long duration. Lemmens et al. [43] studied whether adding haptic stimulation to movies create more emotionally immersive experience. A vibrotactile jacket that contains 64 tactile actuators renders tactile emotion effects to enable viewers experience what the main character is experiencing and thus to become more immersed in the movie. A usability study with 14 participants viewing 7 video clips – with and without tactile stimulation – showed improved immersion with vibrotactile feedback.

A tactile jacket (with a temperature actuator and a heartbeat sensor) is developed to enhance video gaming and movie watching experiences [45]. Similar to the concept of subtitles in movies, synchronized stimuli are sent to the haptic jacket to evoke emotions used on the current scene in a movie or a video game. The jacket was built to display the six universal emotions: love, joy, surprise, anger, sadness, and fear [45]. Results showed that the overall quality of user immersion is enhanced when the haptic jacket is used while watching a movie.

Another interesting application is to promote pleasure by physically connecting humans and pets at different locations over the Internet. Poultry.Internet presented a remote human-pet interaction system using a jacket specially designed with vibrotactile actuators embedded onto a doll resembling the remote pet and a tactile suit that is put on the animal's body [41]. The human can tangibly touch the pet doll, sending touch signals to the pet, and receive haptic feedback from the movement of the pet. A usability study has shown that the system promotes pleasure in both humans and poultry.

An impeding power towards a wide deployment of affective haptics in gaming and entertainment is the complexity and price of haptic interfaces. Existing interfaces are far more complex and expensive compared to existing gaming consoles. Another gap in this area is the lack of haptic "keys" that can reliably induce changes in the emotions of the touched person (similar to the well-known auditory keys that

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are commonly used in entertainment to induce sadness, happiness, etc.).

D. *Affective Haptics for Human-Robot Interaction*

Surprisingly, affective haptics has been little studied in the field of Human-Robot interaction (HRI). In fact, many researchers investigated affective facial and gestural expressions in HRI. Nonetheless, physical contact between robots and humans can enrich the affective experience [88]. For instance, a study conducted by Chen el al. [89] proved that robot-initiated touch could be a successful form of human-robot interaction. Participants had a generally positive subjective experience as indicated by measures such as valence, positive affect, and negative affect, as well as Likert-scale questions about perceived safety, fear of the robot, and willingness to have the robot touch them again.

In future homes, robots would be an integral part of human life (such as humanoids) [90]. They should recognize people as having specific human behavior compared to static object such as tables and chairs, closely interact and collaborate to complete daily activities. Having such a close relationship with humans, robots must read emotions cues from a person, adapt its behavior accordingly, and display emotional and social cues. Such behavior will make robots more natural and simpler to interact with [91]. Researchers are investigating how to endow human-assistant robots with emotions and how to enable them to read social and emotional cues from people. Yohanan et al. [92] (also in [39]) studied the communication of emotions between humans and robots. Several haptic creatures were designed to study a robot's communication of emotional state and concluded that participants experienced a broader range of affect when haptic renderings were applied. Participants were able to recognize the emotional renderings, but the state of arousal is communicated better than its valence.

Researchers have also investigated the simulation of human-animal affective haptic interaction. Examples of notable robots combing touch and animal-like form include Sony's dog, Aibo [93], Shabata's baby seal, Paro [94], and Stiehl's teddy bear, the Huggable [75]. As a therapeutic device, Yohanan and Maclean [21] proposed a furry lap-sized social robot (named the Haptic Creature device) that senses the world via touch, and reacts through ear stiffness modulations, breathing rate, and purring patterns. Experiments showed that the combination of different tactile stimulation techniques allows the perception of some categories of positive emotions. This result led to the development of a furry artificial lap-pet to sense human emotion through touch [39]. The Haptic Creature prototype was extended to integrate a piezoresistive fabric location/pressure sensor [40]. Results showed that 94% recognition rate could be achieved when the system is trained on individuals whereas 86% when applied to a random set of participants. The Haptic Creature recognized which participant touched the prototype with 79% accuracy. A human/poultry interaction is made possible using a doll resembling the remote bird and a tactile suit that is put on the animal's body [41]. A usability study showed that this human-poultry communication system promotes pleasure in both humans and poultry. Another research has investigated the role of touch in communicating emotions between humans and robots [26]. An animal-like robot that can display emotional state through touch is presented. Regardless of the human's gender or background with animals, results demonstrated that tactile stimulation of the robot skin is effective in communicating its state of arousal and valence.

Home-assistant robots have generated significant interest both by the academia and industry, particularly to help the elderly and the disabled [91]. When interacting with a human user, robots should show human-like characteristics in its behavior patterns to allow intuitive partnership. Groten [95] addressed this challenge by proposing a control-theoretically inspired framework for haptic collaboration between two partners. While focusing on dominance behavior, design guidelines for robotic partners in haptic collaboration have been inferred based on experimental studies. Results showed that haptic communication with a robot partner enables the integration and negotiation of individual intentions of human partners.

A common challenge in affective haptic HRI is the creation of affective handshake with a humanoid robot. Few researchers investigated motion models that provide acceptable human-robot handshake interaction [96]. For example, Wang et al. [97] developed an advanced controller that interactively responds to the user behavior during handshake. The evaluation of the controller showed a physical behavior close to human-human handshake. A recent work by Ammi et al. studied how the haptic feedback involved during the human-robot handshake can convey emotions [98]. Experimental results showed that multimodal visuo-haptic interaction with high grasping forces and stiffness of movement resulted in superior discrimination of arousal and dominance by participants compared to visual interaction.

As new opportunities for affective haptic HRI appear, there will be new challenges and research problems. First, the deployment of emotional robots necessitates that test should be conducted in realistic social settings in order to examine the validity, believability and appropriateness of the emotional models adopted and expressions rendered. Second, affective haptic robot must be capable of interacting with dynamic environments in order to provide additional adaptation to the changing environments – perhaps with novel neurophysiologically inspired models. Finally, it is necessary to address several other issues ranging from the psychology of perception of emotions to the control of robotic structures during HRI. Understanding the mechanisms by which robots can touch humans has implications for the design of many HRI applications that range from fostering companionship to therapeutic interventions.

V. Discussion, Challenges, and Trends

In this section, we present a thorough discussion about the findings in this study, highlight research challenges, and provide perspectives for future research and trends.

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A. Discussion

Recent studies with humans have shown that touch is capable of communicating distinct emotions [31]. Studies on social interaction through touch, however, have shown various confounding factors such as gender, relationship status, familiarity, social status, and culture [32][34]. It is likely that the ability of a human to interpret a haptic stimulus and recognize a corresponding emotion depends on far more than the physical properties of the haptic stimulus. Several contextual attributes should be considered for more reliable haptic-based emotion recognition such as interpersonal relationships, gender, synchronized audio/visual cues, cultural differences, etc.

We have found that affect detection through haptic sensors has been an understudied topic. Existing works on the subject were not able to produce yet promising results [28]. Nonetheless, we believe that a multimodal affect detection approach might benefit from haptic-based techniques. Ultimately, humans employ a multimodal system for affect detection and therefore, any artificial system that attempts to mimic this capability must analyze multiple streams of data pertaining to optical, auditory and haptic sensors.

Most of the literature research is based on well-controlled experimental studies that take place in the lab environment. Further research should consider conducting experiments in the everyday (i.e. natural) environment where many other factors may affect the user's emotional state other than the haptic interaction. Therefore, affective haptics is very contextual by nature. The meaning of touch is highly dependent on the accompanying verbal and nonverbal cues of the touching person (and an observer), along with the context in which the touch is applied. Affective haptics systems must take the relevant parameters into account, both in generating social touch and in interpreting it. This issue has boosted a relatively young field of social signal processing [99]. We believe that haptic interaction would be a supplementary modality for filling gaps in human perception, rather than being a sole medium for communication in a multimodal interaction affection communication system. Therefore, appropriate use of the haptic modality in a multimodal system would be sufficient even with a lower fidelity of haptic rendering.

Touch is a private modality of interaction [100]. Users may prefer this form of emotions communication to audio-visual media due to the confidentiality of emotions information. This is probably one of the distinguished features of why haptics could be an ideal means for communicating emotions.

The question of affective display through haptic devices has been more frequently queried. In particular, many studies have focused on the emotional effect of haptic stimuli on humans. Despite the varying applications and experimental setups presented in these works, the following findings seem to be consistent across studies:

- When it comes to affective display through tactile haptic devices, the amplitude of vibration, inter-burst duration, and inter-actuators distance are crucial parameters to stimulate various emotions [5][21][54][101][47].
- Hands are the dominant body parts that are subjected to the haptic stimuli in most studies. However, the haptic stimulus is delivered using various means, such as wearable vibrotactile devices [47], kinesthetic devices [25][36][38] [37] and hand held tactile devices [54].
- Haptic stimulation can be successfully used to achieve a higher level of emotional immersion during media consumption [43] or emotional Tele-presence [66].
- Existing research is demonstrating that haptics is effective in communicating valence and arousal [36][54][53], and emotions of happiness, sadness, anger, and fear [5][25][47]. Less focus has been given to the communication of disgust and surprise.
- The interpretation of haptic stimulation by human beings is highly contextual [54]. Also, the same haptic stimulus may have varying interpretations depending on other modalities of interaction (such as audio and/or visual). Therefore, an ideal affective display system would be based on the fusion of multimodal stimuli to provide the desirable level of user's quality of experience.
- A thorough review of the literature in affective haptics show that not much rigorous research has been conducted; rather there is a long list of curious prototypes aimed at exploring affective haptics. Most of the existing work seems to be discontinued. In order for this area to progress, more relevant and rigorous studies must be sustained.
- Research in this area crosses disciplinary boundaries by bringing together disciplines of haptic technologies, cognitive science, neuroscience, and affective computing. The literature lacks strategies on how to enable various disciplines contribute to affective haptics so haptic interfaces designers can develop more effect solutions. Israr et al. presented an initial effort in this direction where a library of usable haptic vocabulary (called feel effects) is used for designing storytellers and to enrich user experiences in movies is proposed [102]. The library proposes a methodology that allows ongoing additions to the library in a principled and effective way. Other strategies that facilitate the communication across various disciplines include the creation of professional society for affective haptics, organizing events and conferences/workshops, and promoting collaborative research proposals.

B. Research Challenges

The area lacks a structured research agenda. It seems the research community has been looking at affective haptics from diverse perspectives. Here is a summary of challenges that are slowing progress in this area – note that this summary is a compilation of challenges cited in the literature as well as based on the authors experience/opinion:

- <u>*Haptic data acquisition challenges:*</u> This includes the acquisition of sensory suite that adequately captures touch parameters (such as sheer and tangential forces, compliance, temperature, skin stretch, etc.) are lacking. Only after collecting sufficient information about social

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touch would it be possible to apply algorithms that determine accurate appraisal of the touch

- *Cultural challenges:* Many of the ethical issues pertaining to affective haptics apply to the field of affective computing in general. Would it be ethical for a computer to sense a user's physical interactions and/or emotions? Would an ideal haptic-based affective interface compromise user privacy? Are users comfortable with having their touch/feelings sensed? Emotions are ultimately personal and private. Furthermore, affective haptic technologies may capture confidential information about the spontaneous user touch activities as well as their emotional reactions (for instance while interacting with a humanoid robot). Such developments introduce ethical concerns for those whose information is being collected. Finally, some cultures or religions may have a highly restrictive view of all forms of touch and thus it may be unethical to touch a stranger. All these concerns should be taken into consideration when designing an affective haptics system.
- *Intimacy:* Touch raises the problem of violation of personal space in some cultures or for some individuals. Furthermore, the fact that capturing haptic stimuli such as force/torque interaction on various parts of the human body is considerably more difficult than capturing audio-visual properties makes affective haptics more challenging. In other words, haptic behavior is harder to observe in comparison with other modalities such as facial, vocal or postural expression.
- *Rendering:* Once collected, the affective haptics expressions must be rendered faithfully with a haptic device. An unresolved issue is to determine spatial and temporal haptic rendering properties such as the stimulation location on the human body, the duration and frequency of the stimulation, and the synchronization of haptic stimulation with other modalities. Furthermore, it is challenging to create a rich set of distinguishable tactile stimulations by modulating parameters with limited resolution (e.g. intensity) in order to display the subtleties of affects.
- *Intrusiveness:* Current technologies for measuring/displaying haptic behaviors, such as communicating force/torque, require a physical contact between the user and the mechanical system. This constraint reduces the freedom of movements of participants and thus might lead to less natural and a biased expressions of emotions. A new trend in contactless haptic interfaces is picking up where technologies such as air-jet [50][103], acoustic radiation pressure [104][105] and laser [52] can be utilized to produce a tactile stimulation without having any physical contact with the user.
- *Cross Dependency Between Haptics and Emotions:* touch would invoke emotions, which in turn affect the way a user reciprocates. Cross dependencies between touch and emotions must be accurately modeled for a better understanding of haptic-affect interaction.

C. Trends

The studies reviewed in sections 3 and 4 indicate five new trends in the research on affective haptics. This section highlights these trends in detail.

- *Modeling for Synthesized Affective Haptics Sensations:* Affective responses to synthesized haptic sensations are largely unmeasured, modeled or characterized. A better understanding of user perception will aid the design of haptic interfaces that engages emotional communication, with an experience that satisfies rather than intrudes. The goal here is to design a comprehensive model of individual's patterns of affective responses to haptic sensations and perform a formal validation.
- *Ubiquity of Affective Haptics interfaces:* Computation is everywhere, not just on the desk. Affective haptics creates a need and an opportunity in this sparse visual real estate for multimodal and enhanced interaction with virtual spaces and/or remote physical spaces. The state-of-the-art haptic interfaces are mostly desk-based and thus are incapable of realizing ubiquitous affective haptics communication.
- *Contactless Haptic Stimulation:* The design and development of affective haptic interfaces that can effectively trigger emotional reactions is a must for the advancement of the affective haptics research. An elegant solution would be to produce tactile sensations in midair where users are able to get haptic feedback without contact with any physical object or any actuator attached. Research has shown that this can be achieved using air jets [50][53], ultrasound [49][106], and laser [52]. This direction is still in its infancy and thus more work is expected to achieve high fidelity haptic interaction.
- *Emotions and Multimodality:* In an attempt to render affective haptics interaction like human-human communication and enhance its naturalness, research on artificial sensor fusion of multiple modalities is becoming increasingly important in order to reach better accuracy of congruent messages, or to detect incongruent messages across multiple modalities. Accurate interpretation of emotional signals would hence particularly benefit from multimodal sensor fusion and interpretation algorithms.
- *Affective Haptics Repository:* The design of effective affective haptics system relies on successful emotion induction. A novel affective haptics database to increase the availability of haptic emotion stimuli must be created. This database would store carefully chosen haptic patterns that elicit and/or display different emotions.

VI. Conclusion

Though the concept of affective haptics has come out not for a long time, it has witnessed a good deal of progress in the past decade. The study and application of relevant multidisciplinary fields including psychology, social science, computer science and engineering are booming. However, the existing researches look somehow limited in depth and scattered along the various disciplines of study. This paper presented an overview of the recent developments in affective haptics and discussed how the sense of touch can detect or display emotions. The studies reviewed in the present paper show a diverse range of promising applications of affective haptics, ranging from social and interpersonal communication, to health care and assistive technologies for individuals with visual impairment, to gaming and entertainment and human-robot interaction.

The success of affective haptics technologies relies mainly on the high fidelity of haptic interaction (detection and display). We believe a true break-through lies in the development of pervasive, unobtrusive, and natural haptic interfaces that are capable of detecting haptic cues and providing high fidelity haptic rendering, anywhere and anytime, in the same way humans communicate touch with each other. Today, novel technologies bring new opportunities of unobtrusive affective haptics such as mid-air and ultrasonic haptic interfaces. Building unobtrusive and mobile affective haptics interfaces remains an interesting future direction. Another interesting future direction is to study contextualizing touch with other interaction modalities, like audio and video, to help people express affection more directly and accurately. Finally, investigating efficient use of affective haptics in various applications, without compromising the user's confidentiality, will provide an organic integration with the world of computing technology.

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