Touch Technology in Affective Human, Robot, Virtual-Human Interactions: A Survey

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Abstract—Given the importance of affective touch in human interactions, technology designers are increasingly attempting to bring this modality to the core of interactive technology. Advances in haptics and touch sensing technology has been critical to fostering interest in this area. In this survey, we review how affective touch is investigated to enhance and support human experience with or through technology. We explore this question across three different research areas to highlight their epistemology, main findings and the challenges that persist. First, we review affective touch technology through the human-computer interaction literature to understand how it has been applied for mediation of human-human interaction and its roles in other human interactions particularly with oneself, augmented objects/media, and affect-aware devices. We further highlight the datasets and methods that have been investigated for automatic detection and interpretation of affective touch in this area. In addition, we discuss the modalities of affective touch expressions in both human and technology in these interactions. Second, we separately review how affective touch has been explored in human-robot and real-human-virtual-human interactions where the technical challenges encountered and the types of experience aimed at are different. We conclude with a discussion of the gaps and challenges that emerge from the review, to steer research in directions that are critical for advancing affective touch technology and recognition systems. In our discussion, we also raise ethical issues that should be considered for responsible innovation in this growing area.

Index Terms—Affective touch, HCI, HRI, human-computer interaction, human-human interaction, human-robot interaction, automatic recognition of affective touch, emotion, affective states, review, survey.

I. INTRODUCTION

Affective touch pervades human life, from the fervent typing of a message in angry frustration to the pleasing feel of a breeze at the beach, the painful pinch in the inside of a shoe during the day or a comforting hug from a friend. Advance in haptics and sensing technology has created new opportunities for affective touch experiences. This progress has led researchers over the years to explore design of interactive technology that is able to sense and assign meaning to touch as well as produce touch that expresses or modulates affect. In this survey, we review the state of the art in this space to understand the research questions addressed, the methodologies used and the challenges that remain open.

Previous reviews (e.g. [1], [2]) on technology in this context were based on differentiation between discriminative/functional, social, and affective touch. Such distinctions, while having been valuable in establishing the area of research on affective touch, run the risk of limiting the scope of touch interactions considered and the possibilities for introduction of technology in these interactions. We instead take the broader perspective of affective touch being an instance of touch that has associated with it an affective experience. In so doing, we abstract away from neurophysiological roots of touch instances and instead focus on reviewing the status and role of technology in the given touch interaction where affect is of interest. We especially explore technology for affective touch from the lenses of three computing areas (human-computer interaction, human-robot interaction and real-human-virtual-human interaction) to understand the state of the art within each. In particular, we discuss the questions and methodologies that have driven the research in them. This approach provides a more pertinent framework both for identifying different perspectives and gaps as well as bringing together different epistemology and communities that are relevant to the common theme of technology for affective touch interactions. These are important objectives in a space that is still very fragmented and only partially explored.

As such, our survey updates older reviews [1], [2], [3] and further extends them by considering affective touch beyond social settings. For example, we cover self-interaction, i.e. interaction with oneself, e.g. with one’s body or thoughts. In this type of interaction, technology is typically an object or material that directly represents (as a metaphor) the self. We also go beyond the social settings of technology-mediated human-human interaction, real-human-virtual-human interaction and human-robot interaction covered in the more recent review of [2] by including human-technology interaction and human-object interaction. In our classification, human-
technology interaction covers interaction with computers (including mobile devices), computer applications, and digital media/resources, whereas human-object interaction encapsulates interaction with tangible objects beyond traditional computing devices. We treat these separately from human-robot interaction and real-human-virtual-human interaction given the more anthropomorphic and autonomous characteristics of robots and virtual humans as well as the fact that human-robot interaction and real-human-virtual-human interaction are well-defined areas on their own. One of the gains of our wider treatment of the topic of affective touch is that it reveals otherwise inconspicuous issues and technical challenges that need to be addressed for advance in the area. Finally, we extend the previous reviews by considering research on automatic affective touch recognition, typically aimed at personalization of support and experience. We also discuss ethical issues related to automatic recognition and touch technology in general by taking into account lessons learnt across these three areas, and hence also the development we expect in the near future.

The next section briefly highlights the functions and roles of affective touch in traditional human interactions to clarify its significance for the computing community. We then review affective touch across the three computing areas (Figure 1) before bringing the findings together in the discussion section.

II. THE SIGNIFICANCE OF AFFECTIVE TOUCH

The integration of affective touch capabilities into technology has been strongly driven by the positive significance of affective touch in everyday life. For example, in the context of human-human interaction, affective touch is known to be critical for bonding between parent and child [4], and between adults [5]. It further supports homeostatic and allostatic regulation [6] as well as cognitive development, signalling care, reducing sense of solitude, and increasing self-esteem [7], [8]. Possibly less explored but still critical is the understanding that affective touch is influential even during touch that is largely functional as it can provide cues or stimuli to enable co-operation during tasks [9]. Another motivating reason for exploring affective touch in the computing field is the sense of connection and ownership [10] that appears to be triggered by holding and touching an object or a device. Such interactions appear to trigger a desire for care for the object, almost perceived as an extension of the self, together with an increased sense of self-esteem. Neural activity associated with human attachment have further been observed during tactile interaction with cared-for objects but not during visual exposure only [11].

Beyond the function and effect of affective touch, social and affective science researchers have investigated the existence of an affective touch language, i.e. a set of symbols and practices that enable the communication of affective messages. Studies in emotional science [12], [13] have shown that affective tactile expressions are recognized well above chance level for a large set of basic emotions during semi-ecological human-human interactions. Different types of touch are used by parents to elicit specific emotional responses and behaviour in their babies suggesting that the meaning of these different types of touch may be learned very early in life [14], [15]. Studies have also shown that such affective tactile language transfers from human-human interaction to human-object interaction. For example, in [16] it was found that an observer’s perception of what a material feels like is affected by how the observed person’s hand touches it.

As will be seen in our discussion in the next three sections, the beneficial functions of affective touch and existence of
a language have underpinned development of technology to create, support, or mediate affective touch interactions. Such roles for technology grow in relevance as humans increasingly operate in remote environments with limited touch opportunities with others and the virtual environment they inhabit. The increasing pervasiveness of digital technologies, some of which embody artificial agency with touch capabilities and even some sense of self, around us expand the horizon of the possibilities of touch interactions. In the following three sections, we review technologies in human-computer interaction, human-robot interaction and real-human-virtual-human interaction separately given the different questions and roles of technology in these areas. Figure 1 provides an overview of these three sections.

III. AFFECTIVE TOUCH AND HUMAN-COMPUTER INTERACTION

In this section, we review the work on affective touch interaction from the area of human-computer interaction. We identified four contexts that are being investigated in this area: technology-mediated human-human communication, self-interaction supported by technology, augmented human-object/environment interaction and affect recognition to drive personalization. We first explore the roles assigned to technology in these contexts, the research questions addressed, the methodology used and the datasets available to the community. We then discuss the elements (touch sensors/actuators and expressions) of affective touch interactions in these roles.

A. Technology-Mediated Human-Human Touch Interaction

Social and working relations are increasingly being built, developed and maintained over distance. Haptic technology is seen as a promising and convenient medium for recreating the sense of touch in such remote relationships [17]. We identified three main research questions addressed in this area as discussed below.

1) Can technology-mediated touch be a substitute for human-human touch?: A critical question addressed in this area is whether and to what extent technology-mediated touch can replace direct physical touch. Various studies (e.g., [18], [19], [20]) have shown that haptic touch can enhance the sense of presence in remote situations, as well as the sense of intimacy and closeness. The most explored haptic gestures are the ones that involve the use of the hand (such as hand holding, patting, high five, etc.) (e.g., [21], [22], [23]) and hugging through jackets often controlled by augmented dolls ([24], [25]) used to simulate the gesture. A recent study [23] went beyond remote human-human communication to consider social distancing in physical proximity imposed during the COVID-19 pandemic. They found that affective and social haptic feedback has been shown to facilitate communication and understanding in such settings of physical proximity with physical touch prohibited.

Generally based on qualitative approaches, these studies have further highlighted that personalizing aspects of the device beyond tactile parameters contributes to enhancing the sense of intimacy. For example, in [21], allowing each pair of participants to use their hands to build the shape of the physical communicating device triggered a stronger sense of physical connection during its use as well as memories of being together. Results also suggest that wearing a device while creating a haptic gesture may feel more natural in comparison to the use of mid-air feedback. Further, the use of heat feedback in addition to wearing a device enhances the sense of presence and closeness by simulating contact with each other’s skin. Another interesting finding from these studies is the importance of the flexibility of the placement of the device over the receiving body, rather than designing specifically for one body part (e.g., wrist-to-wrist or hand-to-hand). For example, in [22], the use of gloves (Flex-N-Feel) embedded with vibro-tactile actuators enabled the receiving partner to place the glove on the body part they wanted touched. This led participants to explore the possibility of intimate technology-mediated touch rather than just the more common types of social touch.

In relation to intimacy, smartphone based remote kissing is also being explored (e.g., [26]). The use of a set of paired devices allows to send and receive kisses by simulating the warmth and pressure of a real kiss. While in [27] the kiss is enacted and exchanged on a flat surface, others versions of Kissinger ([26]) and the commercial Remote Kissing device ([28]) provide lips to specifically target that body area. Interestingly, the level of realism observed in some devices (e.g. moving 3D lips in Remote Kissing ([28]) lead us to pose the question of when realism contributes to the sense of presence and multisensory experience of touch and when instead could be disturbing. This question could be particularly important for intimate body areas, where the use of overly realistic representations may be perceived as inappropriate or invasive in some case. Study in this directions are still missing.

The above studies suggest the potential for remote touch as a way to overcome physical distance by leveraging all the different modalities of touch (temperature, physical contact, etc.) as well its ubiquitous use across one’s body. However, to fully understand the extent to which technology-mediated touch could substitute physical touch, in-depth longitudinal studies are necessary. These studies are crucial to understanding the factors (including individual differences) and circumstances that may affect the appropriation of remote touch. In addition, it is critical that we start to explore the type of long term impact (if any) of remote touch on relationships to assess its ability to provide benefits similar (or possibly different but still beneficial) to those of physical touch. As we do so, it is important that we consider and understand the processing underlying tactile exchanges such as the emergence of a remote tactile language as discussed below.

2) Does a technology-mediated affective touch language exist or does it emerge?: One of the other questions driving this body of work concerns ascertaining if the affective tactile language observed in human-human physical exchanges ([12], [29]) persists in haptic technology-mediated contexts. A well-known example of studies on this is the one in [30] where the authors demonstrated how the speed, acceleration and shape of a joystick-mediated handshake modulated its perceived affective meaning based on seven emotion categories. This
and works such as [31] provide support for the existence of a technology-mediated haptic language for distance communication.

Moving away from stereotypical expressions, researchers have been interested in understanding whether a technology-mediated tactile language should be predefined or instead can emerge through interaction. This is in line with current research in psychology suggesting that emotional expressions are shaped by and interpreted within the context that they take place [32] rather than being unequivocal in meaning. One of the well-known studies that have started to address this is the one in [33]. The authors showed how partners (lovers) appropriated haptic technology to generate and exchange affective tactile messages during their phone conversations. The sender would build haptic messages by touching a pressure sensor placed on the back of the phone and the receiver would receive the haptic message on their cheek through an inflatable surface placed at the bottom of a smartphone. Duration and type of finger movements would modulate the speed of inflation and type of vibration the receiver could perceive on the cheek. A longitudinal study showed that over time, the initial undefined set of possible haptic patterns evolved into a couple-specific affective tactile language.

Similarly, a more recent study [18] leveraging a pair of digital gloves embedding a variety of actuators (vibrator, pressure, heat) showed that the construction and interpretation of multimodal tactile messages was shaped by a variety of contextual factors. Working with different types of pairs (co-worker, friends, family, lovers), their study showed how social, environmental, personal (i.e., knowledge of each other), physical and affective factors were used to create and assign meaning to each dimension of the haptic feedback. Differently from [33], this study showed that the same haptic pattern may have a different meaning within the same couple and that the meaning is modulated by those contextual factors. For example, the sender’s understanding of the thermal environment that the remote receiver was in affected their interpretation of the (dis)pleasure that a certain amount of heat may create. Consequently, such a perception played a role in the way temperature was used to define the valence of the message. Hence, it is clear that having a simple creation-delivery model in mind limits the design of technology that can emulate social touch at a distance. In line with this, [34] suggests that social touch should instead be studied from the perspective of its impacts (non-verbal effect model) on both the sender and receiver, rather than from a message creation and interpretation perspective.

3) Is technology-mediated touch effective in the wild?: One of the limitations of the above studies is their limited ecological validity. Some of the studies have attempted to overcome this limitation by providing participants with affective social scenarios to explore through the device or by running a study of limited length in the wild (e.g., [18]). As commercial, stable affective-touch devices (e.g., ixubear, FeelHey) for distance relationships appear on the market, longitudinal studies become more feasible. A recent example of such studies is the one by [35]. They leveraged FeelHey, an e-bracelet that people can wear and use to send gentle squeezes to each other’s wrists when at a distance. The bracelets communicate through bluetooth connection with a smartphone app. Using a qualitative approach, they engaged romantic couples living separately during the COVID-19 lockdowns. The study results suggest that technology-mediated touch has the potential to enhance the sense of presence as well as the salience of multimodal exchanges. However, participants considered FeelHey haptic feedback only as an extra channel that could enhance other forms of media-based communication (e.g., video call) in supporting their relationships. Their longing for physical touch remained unchanged, i.e., not fully satisfied. One reason for this result is perhaps the simplicity of the feedback that such devices still offer.

B. Touch-Mediated Interactions with The Self, Objects, or Digital Devices/Media

Beyond supporting remote human-human interaction, technology with affective touch capabilities has been investigated from the perspective of supporting the individual. We have identified three main research problems explored within this and review the body of work below.

1) How can touch technology facilitate self interaction and reflection?: Individual selves are critical components of any social interaction [36], with each individual making appraisals of self, environment, and others that influence self-regulation, i.e., reflection and behaviour [37], [38]. Findings of relationships between loneliness and social media usage, for example, highlight the significance of internal processes in mediating the role of technology in creating or enabling social interactions [39]. Yet, most of the discussion on affective touch is usually centred on the social to the exclusion of self interactions which not only influence it but are further relevant outside of instances of social transactions.

While research in the area is very minimal, there are a few studies that highlight possibilities for technology design to enable interaction with the self through touch. An example is the water-based tactile interface of [40] which participants used to practice dissolution of thoughts as a strategy for distancing themselves from their thoughts as a mindfulness discipline. The device of [41] was similarly designed to facilitate self-adaptor gestures, i.e., self-touching either intentionally or unconsciously used to regulate emotional experience (such as self-hugging or self-stroking). Another example is the pain object of [42]. The authors explored the use of the object for expressing pain (through squeezing), externalising it in the object, and then distancing oneself from it by physically throwing the object away from one’s body. To facilitate externalisation of pain in the object, tactile feedback that represents the object’s embodiment of the expressed pain is provided to the user.

In a special class of self-interaction interfaces, the mediating object is itself a part of the user as is the case with the system of [33] used to communicate touch of the user’s prosthesis to a non-prosthetic region of their body with the aim of facilitating embodiment of the prosthesis. We also include under affective touch self-interactions, experiences where although the tactile object or material does not directly represent the self, it is
designed to enable real-time self-exploration or self-awareness. An example is the setting of [44] in which participants caressed a mobile device screen to keep focused attention during mindfulness sessions. A similar class of affective touch interfaces is the art medium in [45] that tangibly represents real memories. The memories capture affective experiences of the memory owner(s). The art form that externally embodied them was designed to invoke and enable affective interaction through touch, by the memory owner(s) themselves or by other observers. To transform memories into tangible object, written forms of the memories were encoded as DNA that was then borne by bacteria, producing biofilm which became tangible representation of the memories. For display of the now tangible memories, i.e. the biofilm material, it was overlaid on a base object (an animal skull).

2) In what ways can augmented touch interactions with objects, media and environment be of value?: Beyond self-interaction, affective touch has been investigated as a possible way to enhance our interaction for a variety of purposes. For example, [46] designed an expressive thermostat control knob to foster energy savings behaviour. The thermostat knob reacts in real time, to a tactile-based user setting, with either submissive acceptance, assistive, or dominant behaviour. They further explored expressions of disagreement and contentment by the knob. Submissive acceptance, for instance, could emerge when the user overrides the thermostat’s recommended settings even when it attempts to suggest a compromise (temperature). The thermostat could express disagreement with the user when proposing a middle ground between its original recommendation and the user’s specification, before finally deferring to the user when they insist on their own setting. Another similar work is the interactive door knob in [47] that responds to previous ‘affectionate’ touch ‘affectively’, i.e. vibrating, shaking its tail, and blinking its lights, altogether designed to emulate the experience with a pet which is excited when its owner returns home.

Artificial touch interactions have also been explored for encoding affect information in the use of digital technology. Examples of studies in this area include the use of vibrotactile sensation to enhance a user’s affective experience of audiovisual media [48], [49], [50], [51], [52], or to present relevant affective [53] or non-affective information, e.g. mobile device notifications [54], to the user.

3) Can technology sense from touch how we feel, for the purpose of adapting to our needs?: The above forms of technology for affective touch interactions are designed to either invite tactile gestures known to elicit specific experiences, or to provide stereotypical haptic feedback associated with some specific affect. The interpretation of the meaning of the tactile patterns is left to the person receiving or creating them. A different direction of investigation is the design of technology that can infer the affective experience of its user from their touch behaviour, so as to drive personalization of a response to them or tailoring of their tasks.

An example of work in this direction is [55]. The authors proposed a fidget ball that can detect the user’s emotional experience from how they handle the object, e.g. through squeezing, stroking, or shaking. The object responds to the inferred emotion of the user by displaying a portion of the lyrics of a song in their database that reflects the emotion. Other examples include [56] where the user collaborates with a computer. The system detects moments when the user signals the intention to relinquish (or take back) control in order to facilitate role exchange in real time. [57] targets stress, with the aim of delivering stress reduction intervention to the user; and in [58], user satisfaction with web search results is the experience of interest for the purpose of enabling automatic ranking of results. In similar work by [59], the use case proposed is the application of such interfaces to capture the user experience to inform technology design stages.

Unlike research discussed in Sections [III-B1] and [III-B2] largely driven by qualitative methods aiming to understand touch experiences to inform the design of sensors and actuators, research here follows a quantitative approach typically using machine learning techniques. Automatic recognition models are built to map tactile patterns onto affective states. In order to drive this body of work, there is a growing but still limited collection of datasets, some of which are available to the research community. Tables I and II give an overview of these datasets. Other than the last four datasets in Table I that emerge from human-robot interaction and real-human-virtual-human interaction areas (discussed later in Sections [IV] and [V]), the datasets in this table cover settings of interactions with objects or mobile devices (e.g. typing, mobile game play).

Different aspects of human touch expressions are captured in these datasets. These data themselves and/or features extracted from them have been used as input data for the affect recognition models. Occurrences of touch is one category of such characteristics. Events of touch are usually captured as a timestamp [60], [59], [61], [62], [57], [63], [64], [65], position [66], [67], [68], [63], [65], [69], and/or keyboard key [62], [57], [64]. Features such as mean [63], count [58], [61], [62], [68], [60], [70], deviations from expected patterns [59], [61] may be further extracted for analyses or modelling. There has also been consideration of other attributes which capture not just occurrence but also method/behaviour of touch, e.g. duration or orientation [58], [70], pressure [67], [58], [71], [57], [68], [63], [70], [55], [72], size [58], [68], [70], [69]. Other features that have been extracted to capture touch behaviour include directness index [66], number of changes to/from the dominant positions [69]. There is an additional class of touch characteristics that is focused on temporal attributes such as duration [66], [58], [59], [61], [71], [68], [70], [63], [73], time between touch events [59], [62], [71], [70], speed or acceleration [66], [58], [68], [63], [70], [65].

As can be seen from the tables, automatic detection performance of touch expressions have ranged widely across the different affect categories and levels of naturalness. A variety of standard machine learning algorithms have been used, although random forest and support vector machine are explored the most. Deep learning techniques, particularly the use of autoencoders [65], [55], have only been applied in more recent studies, highlighting that work on this affective modality is still well behind the work on other modalities, e.g. body expressions [74]. In addition, the existing data collection is still very much based on basic affective dimensions and
basic emotion categories. We expect that as the work on the automatic recognition of affective touch matures, there will also be exploration of more complex (and more pertinent) affective situations and expressions. Advances in such tools may lead to a wider uptake of personalization approaches in the other affective touch investigations discussed in the previous sections.

Finally, we can observe from the list of features above (and in the tables) how these datasets provide a very limited representation of touch as they only capture its kinematic and pressure dimensions. They do not consider other dimensions (e.g., temperature) of touch that emerge as important in affective touch technology as discussed earlier and in the following. In addition, the datasets and hence the algorithms trained on those do not consider other factors that may affect the meaning and interpretation of affective touch. It is critical that we consider these gaps and call for a better understanding of affective touch as a multimodal and multi-factor channel when we design affective touch recognition systems. It is important we build datasets that are more representative of touch and reflect the wider space of application of this technology, for it to be effective and useful.

C. Touch Sensors and Actuators

The body of work discussed in the previous section has been strongly supported by advance in low-cost wearable haptic and sensing technology. We discuss the state of the art in these areas of human-computer interaction and ubiquitous computing under three categories: the body areas targeted, the anatomy and meaning of touch and the actuator and sensors used in delivering and capturing tactile messages.

1) Body areas define the type of interaction: Although the finger is the typical region of interest due to the prevalence of touchscreen-based interfaces, there are a number of applications where the full hand — the palm (e.g., [53], [46], [55]) or back (e.g., [49], [51]) — has been the target. The back side is typically targeted to provide tactile sensations to the user; conversely, the palm side is usually employed to obtain touch-based input from the user. The few exceptions to this include the thermostat knob application in [46] for which force feedback is experienced via the palm. Similarly, with the gamepad in [53], vibrotactile patterns are experienced on the palm.

The neck, chest, back, and arms have also been involved in delivering tactile experience to the user [52], [41], [48], [79], [80], [50], [51]. In [48], different anatomical regions are proposed for different affective experiences. For example, they found that thermal stimuli in the neck and abdomen combined with heartbeat actuation on the left side of the chest are recommended for portraying love, whereas air pump patterns all over the chest are proposed for sadness.

2) Subareas of the body further specify meaning and social rules: While studies in psychology have shown that gross body parts involved may affect the interpretation of the message (e.g., [12]), human-computer interaction studies have shown that even localized areas in the body have their own role in modulating the affective meaning of touch. Using the Flex-N-Feel gloves, [22] showed that the same sensation could be perceived and interpreted differently in different body locations possibly due to differences in skin sensitivity. For example, vibration on the belly resulted in a sensation of tickling when the gloves were placed on one’s belly. [81] investigated the level of sensitivity of different areas of the sole to identify the ones more sensitive to their tickling device and fine tune the design to that subregion.

In [18], [82], the hand was perceived as formed by subregions of different levels of affective valence. This association was based on the level of skin sensitivity of the subregion (and hence the level of pleasure or displeasure of the received haptic feedback) as well as on the level of people’s perceived control in accepting or avoiding the haptic feedback in that subregion. For example, in [82], people perceived more control on the subregion at the bottom of the thumbs than with other fingers. Due to the higher degree of freedom of the thumbs, people felt that a person could more easily avoid (if they wanted) mid-air haptic feedback delivered by the device. In both [18] and [82], the internal part of the hand was considered to be more intimate than its external regions and is hence a space for haptic feedback between intimate persons rather than between strangers.

3) Touch sensor and actuator technology: A variety of sensors and actuators have been explored to capture and simulate touch respectively. They are typically one of: anthropomorphic, fluid, robotic, touchscreen-based, otherwise off-body, or wearable.

For instance, the self-adaptor device of [41] was made up of an anthropomorphic device that used micro switches and pressure sensors to capture human touch expressions (e.g. hug) that the user wanted transferred to their own body. A vest (wearable) that comprised multiple McKibben air muscle actuators was then used to deliver the tactile experience to the user. Other instances of wearable actuators are the gloves in [49] and the jackets in [52], [50], [51] that used vibration motors to provide vibrotactile sensations to the user. Where the actuators in [52], [49], [50] used vibration motors, [51]’s system was based on shape memory alloy. A different kind of wearable actuators are those that produce thermal sensation, such as the thermo-electric coolers used in [48].

An example of a fluid-based system is the water-based interface in [40] which used the camera of a tablet placed under a transparent water container (a bowl) to capture touch interactions; another case is the use of air jets to deliver tactile sensations [80]. More complex forms of fluid haptic devices are emerging such as mid-air feedback [82]. Fluid-based systems have the advantage of removing the need to wear a device. However, the sensations created and explored in the context of affective touch are still limited, although it opens up interesting opportunities. Other types of off-body systems that have been used (beyond touchscreens) include pressure/force-resistor sensors [55], contact microphones (sensors) [54], vibration actuators [54], [53], and brushless gimbal motor actuators [46]. An instance of a robotic interface is the force-sensing haptic device used in the human-computer collaboration system in [56] to capture the human’s expression of intention to hand over or take back control to/from the
<table>
<thead>
<tr>
<th>Reference (dataset name, if applicable)</th>
<th>Year</th>
<th>Touch context</th>
<th>Affective experiences captured</th>
<th>Touch data</th>
<th>Other data</th>
<th>Number of data subjects</th>
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<th>Best performance</th>
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<tr>
<td>Gao et al. [66]</td>
<td>2012</td>
<td>Mobile game play</td>
<td>Excited, relaxed, frustrated, bored</td>
<td>Touch position, contact area, duration</td>
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<td>15</td>
<td>Discriminant analysis; MLP; SVM</td>
<td>77.0% (accuracy, 4 classes, LOSOCV)</td>
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<td>2012</td>
<td>Maths problem solving</td>
<td>Confidence</td>
<td>Touch position, z-axis acceleration of the tablet due to touch pressure, start and end times</td>
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<td>-</td>
<td>-</td>
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<td>2013</td>
<td>Web search</td>
<td>Satisfaction</td>
<td>Touch event type (e.g. click, swipe, zoom), direction, number of contact points, pressure, contact area</td>
<td>-</td>
<td>26</td>
<td>Bagging (based on decision trees)</td>
<td>86.6% (normalized discounted cumulative gain, 10-fold CV)</td>
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<td>2013</td>
<td>Typing</td>
<td>Arousal, valence</td>
<td>Number of key presses, number of backspace uses, time of key press</td>
<td>Age, gender, experience, education level</td>
<td>152</td>
<td>-</td>
<td>-</td>
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<td>Bhattacharya [59]</td>
<td>2015</td>
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<td>Positive, negative, neutral</td>
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<td>-</td>
<td>57</td>
<td>Linear regression</td>
<td>90.5% (accuracy, 3 classes, hold-out validation)</td>
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<td>Phone interaction</td>
<td>Negative, positive, neutral</td>
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<td>57</td>
<td>SVM; Maximum entropy model; K-means clustering; Conditional random fields; Linear regression</td>
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<td>2017</td>
<td>Typing</td>
<td>Happy, sad, stressed, relaxed</td>
<td>Time of touchscreen keyboard touch event</td>
<td>Application name, non-alphanumeric character typed</td>
<td>22</td>
<td>Logistic Regression; SVM; Random forest</td>
<td>73%(AUC, 4 classes, person-dependent 10-fold CV)</td>
</tr>
<tr>
<td>Hadjidimitriou et al. [71]</td>
<td>2017</td>
<td>Typing</td>
<td>Happy, sad, afraid, angry, surprised, disgusted, neutral</td>
<td>Key press duration, time between key presses, pressure</td>
<td>Age, gender, education level, experience</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Exposito et al. [57]</td>
<td>2018</td>
<td>Typing</td>
<td>Valence, arousal, stress</td>
<td>Key press time, position, pressure</td>
<td>-</td>
<td>11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Heraz and Clynes [68]</td>
<td>2018</td>
<td>Phone-based touch tasks</td>
<td>Anger, awe, desire, fear, grief, hate, laugh, love, neutral</td>
<td>Touch position, contact area, amount of force</td>
<td>-</td>
<td>20</td>
<td>Random forest</td>
<td>91.1% (mean F1 score, 2 classes, 10-fold CV)</td>
</tr>
<tr>
<td>Ruensuk et al. [70]</td>
<td>2019</td>
<td>Social media browsing and chat</td>
<td>Positive and negative affect, low and high arousal</td>
<td>Time (since last touch, before chat response), touch (area, pressure, amount, duration, speed, acceleration, angular orientation, altitude), distance between touch start and end positions, number (touches outside &amp; inside keyboard area, special keys use)</td>
<td>-</td>
<td>49</td>
<td>SVM</td>
<td>61.0-76.0% (F1 score, 3 classes, hold-out validation)</td>
</tr>
</tbody>
</table>

CV - Cross-validation; LOSOCV - Leave-one-subject-out cross-validation
MLP - Multilayer perceptron; SVM - Support vector machine
### TABLE II
**DATASETS FOR AFFECTIVE TOUCH COMPUTING (cont’d)**

<table>
<thead>
<tr>
<th>Reference (dataset name, if applicable)</th>
<th>Year</th>
<th>Touch context</th>
<th>Affective experiences captured</th>
<th>Touch data</th>
<th>Other data</th>
<th>Number of data subjects</th>
<th>Automatic detection algorithm</th>
<th>Best performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hashemian et al. [63]</td>
<td>2019</td>
<td>Mobile game play</td>
<td>Happy, sad, angry, surprised, scared, disgusted, valence, arousal</td>
<td>Touch position, pressure, timestamp</td>
<td>-</td>
<td>25</td>
<td>Decision tree; RF</td>
<td>71.9 % (accuracy, 4 classes, LOSOCV)</td>
</tr>
<tr>
<td>Shapiro et al. [55]</td>
<td>2019</td>
<td>Fidget object handling tasks</td>
<td>Anxious, angry, sad, tentative, certain, positive emotion</td>
<td>Pressure data</td>
<td>-</td>
<td>16</td>
<td>Autoencoder &amp; MLP</td>
<td>2.78 (average MSE, 0-99 scale, hold-out validation)</td>
</tr>
<tr>
<td>Balducci et al. [72]</td>
<td>2020</td>
<td>Swipe pattern tasks</td>
<td>Depression, anxiety, stress</td>
<td>Pressure data</td>
<td>-</td>
<td>115</td>
<td>Decision tree; RF</td>
<td>73.4-74.1% (accuracy, 5 classes, 10-fold CV)</td>
</tr>
<tr>
<td>Wampfler et al. [65]</td>
<td>2020</td>
<td>Chat</td>
<td>Valence, arousal, dominance, anger, sadness, happiness, surprise</td>
<td>Touch time, touch position</td>
<td>-</td>
<td>70</td>
<td>Pretrained variational autoencoder &amp; MLP</td>
<td>63-67% (accuracy, 3 classes, LOSOCV)</td>
</tr>
<tr>
<td>Qi et al. [73]</td>
<td>2021</td>
<td>Password entry</td>
<td>Happiness, fear, disgust, sadness</td>
<td>Touch data</td>
<td>-</td>
<td>9</td>
<td>RF</td>
<td>78.3% (accuracy, 4 classes, unspecified validation method)</td>
</tr>
<tr>
<td>Niewiadomski and Sciutti [69]</td>
<td>2021</td>
<td>Object handling tasks</td>
<td>Anger, sadness, excitement, gratitude</td>
<td>Touch position, activity duration</td>
<td>-</td>
<td>11</td>
<td>SVM; Localized multiple kernel learning</td>
<td>75% (accuracy, 4 classes, LOOCV)</td>
</tr>
<tr>
<td>Human-Animal Affective Robot Touch (HAART)* [75]</td>
<td>2013</td>
<td>Zoomorphic object petting</td>
<td>Stroke, scratch, squeeze, pat, rub, pull, contact without movement, no touch</td>
<td>Touch position, pressure, touch data</td>
<td>-</td>
<td>16</td>
<td>RF; MLP; logistic regression; Bayesian networks</td>
<td>86% (accuracy, 8 classes, 10-fold CV)</td>
</tr>
<tr>
<td>Corpus of Social Touch (CoST)* [76]</td>
<td>2014</td>
<td>Robot arm</td>
<td>Grab, hit, massage, pat, pinch, poke, press, rub, scratch, slap, squeeze, stroke, tap, tickle</td>
<td>Pressure data, touch position</td>
<td>-</td>
<td>31</td>
<td>SVM; Bayesian classifier</td>
<td>54% (accuracy, 14 classes, LOOCV)</td>
</tr>
<tr>
<td>Ku et al.* [77]</td>
<td>2019</td>
<td>-</td>
<td>Stroke, rub, press, light continuous touch, hit, no interaction</td>
<td>Pressure data, vibration data, touch data</td>
<td>-</td>
<td>5</td>
<td>Hidden Markov Model; Long short-term memory neural network; CNN</td>
<td>87.8% (accuracy, 6 classes, hold-out validation)</td>
</tr>
<tr>
<td>Tianjin University TouchGet* [78]</td>
<td>2022</td>
<td>Social robot</td>
<td>Hit, massage, rub, pat, poke, tap, push, press, scratch, tickle; Happy, excited, surprised, afraid, angry, disgusted, sad, depressed, tired, calm, relaxed, content</td>
<td>Pressure data, touch position</td>
<td>Gender</td>
<td>15</td>
<td>CNNs</td>
<td>92.4% (10 gesture classes); 72.5% (12 affect classes) - both accuracy &amp; based on person-dependent hold-out validation</td>
</tr>
</tbody>
</table>

CV - Cross-validation; LOSOCV - Leave-one-subject-out CV; LOOCV - Leave-one-out CV; MSE - Mean squared error
RF - Random forest; MLP - Multilayer perceptron; SVM - Support vector machine; CNN - Convolutional neural network
* - Datasets for human-robot interaction context
D. Expressions of Touch in Affective Technological Interactions

As discussed and reviewed in the next four sub-subsections, various studies have investigated how people assign affective meaning to the various modalities and dimensions of artificial touch. This body of work is organized here according to the main modalities (vibrotactile, pressure, force feedback and its shape, thermal and touch gesture type) used to deliver affective touch. The findings aim to provide specific parameters for a designer or engineer to create haptic sensations with affective meaning. Indeed, it tends to combine the more typical quantitative approaches with richer study protocols including interfaces for co-designing or tuning the parameters for personalized haptic sensations according to the specific body area targeted. It should however be noted that tactile messages are generally formed by all these modalities together even if they are often explored in isolation or in limited combinations. We additionally review the types of human touch gestures that technology has so far been designed to capture or initiate in its human user.

1) Vibrotactile expressions: Vibrotactile patterns are perhaps the most explored mechanism for delivering tactile sensations to the user. Intensity and frequency (carrier and/or envelope) have usually been the vibration parameters leveraged for altering affective experience [52]. [53]. [49]. [50]. [54]. [79], although variables such as duration, continuity, direction, (dynamic) spatial distribution and waveform have also been explored [50]. [54]. [79]. [52]. [53]. Findings in [85] suggest that vibration (carrier) frequency is more closely linked to valence, with increase in valence as frequency is increased. Meanwhile, vibration intensity is more strongly related to arousal, with higher intensity resulting in increased arousal. [86] obtained similar findings for intensity and additionally found a strong association between intensity and dominance. A strong relationship with arousal was also found for vibration duration in [85] where lengths between 50 and 2,000 milliseconds were considered. Increase in duration was found to increase arousal. The design of the vibrotactile pattern of the wearable jacket in [50] is consistent with these findings. For instance, discontinuous, downward-outward, low frequency and high intensity vibrations were used to convey high arousal and low valence affect; and continuous, upward, high frequency and low intensity vibrations were employed for low arousal and high valence affect. However, a different design was used for the wearable gloves in [49], with coolness represented as low frequency, low intensity vibrations; excitement as low intensity, high frequency vibrations; and suspense as high intensity, high frequency vibrations.

2) Pressure, force feedback and shape expressions: Pressure, force feedback and shape change have also been studied. For example, [79] compared vibration and pressure actuations. Their findings suggest that positive and negative valence ratings were better distinguished using pressure than with vibrations although the waveform used, the intensity of the actuation and the anatomical region it is delivered to also moderate the distinction. The findings also show that low intensity and ramp waveform pressure (on the back) was more associated with positive valence; and high intensity, step waveform pressure (also on the back) was associated more with negative valence. This is similar to the finding in [80] that while high intensity air jets were found more arousing and dominant, they were rated as less pleasing. In [51], high intensity, high frequency compression on the torso and shoulder was designed to stimulate fear, and sadness was set up to be aroused using low intensity, low frequency compression on the shoulder and neck. For the thermostat knob in [46] where force feedback and shape change were used to give passive and active feedback respectively, discontinuities in force feedback and fast, jerky shape movement were proposed to express disagreement. Closing of the shape to a minimum size was further suggested for contentment and submissive acceptance, with slow shape movement in the case of the latter.

3) Thermal expressions: Although less explored compared to the other forms of technological expression, thermal representation is another medium. For example, in [48], warmth was explored for presenting love and anger to the user. Findings in [87] suggest that whereas thermal warmth which unlike coolness is usually associated with positive valence, more intense levels of warmth are perceived as negative. A more complex pattern was observed in [18] where beyond stereotypical meanings associated with temperature, contexts and expected preferences were used to either create or interpret a digital tactile message. In the study, a pair of mittens integrated other modalities (pressure and vibration) with heat. A peculiarity of the device was that the user could switch off some modalities if not useful for the affective message to be communicated to their human partner. Speed of activation, changes and randomness in the feedback pattern were highlighted as ways to modulate arousal, and to some extent valence, of touch. For example, random changes within the feedback and high intensity were associated with messages related to fear and panic as well as playfulness. Instead, still or cyclic patterns were generally interpreted as calm, loving and supporting messages. It should also be noted that the randomness of modalities was associated with confusion and fear.

4) Human touch gestures: The affective meaning of touch is not only informed by the kinematic and thermal characteristics of the technology creating haptic sensation but also by the gestures used by humans to express (or experience) touch, as shown in [12]. The types of interactions (e.g. swipe, tap, stroke, zoom) afforded by touchscreen phones or tablets dominate the collection of affective touch expressions. Still, other forms of sensors discussed above add some variety. The anthropomorphic interface in [41], for example, allows the user to express both an embrace and stroking movements (e.g. for self-soothing). In the water-based system in [40], users had the flexibility to either lightly disturb the water surface or move more actively beyond it. With the fidget ball of [55], the user could scratch, twist, squeeze, tap, punch, rub and massage, or simply hold the object. For tablet- or phone-based interactions, there are also expressions that go beyond the traditional means of interaction with a smartphone, e.g.
users of the mindfulness application in [44] interacted with the interface using slow, gentle continuous stroking. Recent work has also attempted to simulate the richer language of social gestures (e.g., patting, caressing, etc.) together with the parameters that affect emotional perception (e.g. [88], [83], [89]).

In this section, we have reviewed the main research questions around technologies in affective touch interactions addressed in the field of human-computer interaction. We now review the space of human-robot interaction in the following section. Some of the insights from human-computer interaction apply, but we aim to highlight the specific problems around affective touch between a human and a robot.

IV. AFFECTIVE TOUCH IN HUMAN-ROBOT INTERACTION

The complex role of touch is an increasingly appreciated horizon for human-robot interaction research. The explicit and implicit registers of touch, both human-to-robot and robot-to-human, have opened up pressing questions in design and ethics about embodiment, communication, care, and human affection [90], [91]. A distinctive element of human touch is conveying affect and empathy, which not only encompasses the recognition of the artificial robotic features but also determines the sensori-motor coordination during human-robot interactions. In this section, we review the role of affective touch in human-robot interactions from two perspectives: humans touching robots and robots touching humans.

A. Humans Touching Robots

Humans incorporate a multilevel process for the perception of affective sensation: 1) primary emotions/signals generated at the sensory level; 2) perception and responses integrated with a memory system at the schematic level; and 3) predictive processing with prior experience at the conceptual level [92], [93], [94]. Enabling the robot to recognize affective expression when being touched by a human relies on a similar architecture: 1) sensory level input via tactile sensors on the robot; 2) perception and memory system; and 3) recognition algorithms based on prior experience. This human-inspired approach is a more complex architecture for sensing and recognizing touch than discussed in the human-computer interaction literature (Section III-B3). This is due to the sense of agency and self that robots are expected to embody.

1) Artificial skin and tactile sensors to detect human touch: Large-area tactile sensors have been developed as a solution for sensitive artificial skins in robots. Unlike touch-augmented objects and wearables discussed in the previous sections, the metaphor “skin” highlights how the work discussed in this section is driven by the simulation of humans (or animals). Enabling a robot to “feel” and “understand” the emotions conveyed by human touch would ultimately rely on the development of such technology. The well-used analogy between humans and robots further highlights the expectation to cover a large area of the robot (if not the full robot) with fine and complex capability that we expect from human or animal skin. In humanoid robots, the skin is commonly attached to the robot’s torso (chest, abdomen, or back).

The review by [95] covers important elements that enable a robot to detect physical contact with a human, including the types of sensors used to detect the interaction. From a hardware perspective, solutions that are determined by the types of physical interactions between the human and robot were categorized in [95] as a hard shell, a flexible substrate, or no covering. Research in this area has usually been conducted concurrently with user studies on the social meaning of touch gestures [76] for specific physical interactions between the human and robot. An example of a sensor is the 10.8 × 10.8 cm² flexible robotic skin developed by [96]. The robotic skin contains 64 sensors that measure proximity, contact, and force. The skin also includes onboard microcontrollers for affective touch recognition, with a classifier that can differentiate between pat, rub, scratch, stroke, and tickle touch gestures.

In general, researchers have proposed and demonstrated a wide variety of large-area tactile sensors that can potentially be used for affective touch recognition. These technologies usually consist of a number of discrete sensors connected in an array, responding to pressure, proximity, or temperature change when touched. Approaches to sensing range from the use of organic field-effect transistors [97] or piezoresistive semiconductors to transducers that use capacitive, magnetic, piezoelectric, optical, or other differences [98]. By imitating the human skin, deploying large-area tactile sensor skin on a humanoid robot has promoted research in a number of applications, from cognitive ability development investigations [99] to daily human-robot interactions [100], [101]. Multimodal tactile sensor skins that can detect different types of tactile information are emerging areas in the field. For instance, CelluARSkin [102] is able to detect proximity, vibration, temperature, and pressure.

2) Algorithms for the recognition of affective touch: With the current advances in machine learning and increasing computation power, information collected by a robot’s sensor skin during touch can be effectively interpreted to recognize the human’s affective experience. However, similar to the challenge in the human-computer interaction field, this area of work still requires large training datasets collected in specific interaction scenarios relevant to the application. Another technical challenge that remains is the excessive and redundant information in both spatial and time dimensions due to the interaction model.

Implemented with respect to a 2×2 sensor array fabricated using liquid metal embedded silicone elastomer as a resistive element, [103] trained a recurrent neural network to distinguish between ten different types of pokes and rubs from human users with an average classification accuracy of 97%. Using publicly available affective touch datasets (CoST and HAART datasets, see Table [I], [104] compared a convolutional neural network, a convolutional-recurrent neural network, and an autoencoder (recurrent neural network) for recognizing social touch gestures. The results showed that deep learning approaches provided similar levels of accuracy (around 30-70% across gestures) and enabled gestures to be predicted in real-time at a rate of 6-9Hz. Conventional methods such
as Bayesian classifiers and support vector machines have also been used for recognizing social touch gestures [76]. In general, these methods use machine learning algorithms for classification by extracting the spatiotemporal features and statistical features of touch motion similar to the ones discussed in Section III-B.3. Several other studies on the classification of touch gestures based on the CoST or HAART dataset can be found in [105], [106], [107], [108], [109].

A recent study in [78] considered touch gesture samples as 3D spatiotemporal signals that include shape, appearance, and motion dynamics for emotional state perception. A decomposed spatiotemporal convolution, factorizing the 3-D kernel into three 1-D kernels by tensor decomposition, was designed for feature representation from the dataset. The touch dataset from Tianjin University (TouchGet, as seen in Table I) was acquired with a 10 × 10 pressure sensor array, including 10 types of touch gestures and 12 types of discrete emotions with 15 participants sampled at 50Hz. The results show an accuracy of up to 92.41% and 72.47% for touch gesture and emotion recognition, respectively, with the proposed method.

Algorithms designed for recognizing affective touch with multimodal tactile information are limited in human-robot interaction (as in human-computer interaction). Despite the various types of mechanoreceptors in the human skin, the capture and interpretation of touch by robots are constrained to unimodal tactile information. The work carried out in [77] shows an interesting attempt to break ground in this direction. The authors collected data (as shown in Table I) with a multimodal-sensing modular tactile interface prototype incorporating both pressure and vibration sensors. Classification was implemented with a hidden Markov model, long short-term memory neural network, and a 3D-convolutional neural network, which obtained the best accuracy of 88.86%. Memory requirements of affect recognition models have also been investigated, showing the feasibility of being implemented on onboard microcontrollers to perform recognition with the skin itself.

3) Behaviour studies on humans touching robots: Behavioural studies have been widely adopted in the field to characterize, evaluate, and analyze human-robot interactions when a robot perceives touch and interprets affective experiences. In general, studies on humans touching robots can be categorized into two types: touching humanoid robots and touching non-humanoid robots. The appearance and texture of the robot provide a contextualized experience for affective responses.

Research on humanoid robots that replicate human features for service, entertainment, manipulation, and healthcare has a long history in the robotics community [110]. Various designs have been developed, ranging from child to adult size. Successful child-sized robots include iCub [99], DARwIn-OP [111], NAO [112], igus [113], Poppy [114], KASPAR [115], and Pepper [116]. Manufacturing larger adult-sized robots is more challenging, but they have received increasing attention in the last two decades. Well-known adult-sized robots include Honda Asimo [117], NimRo-OP2X [118], Toyota THR3 (Toyota Motor Corporation, Japan), Atlas (Boston Dynamics, USA), and DLR-TORO [119]. Detailed technological aspects of these humanoid robots can be found in several review papers [120], [121], [122].

Studies on human behavior based on humanoid robots have investigated user demographic differences, the conveyance of emotions, and personality traits within the scope of specific tactile interaction scenarios such as handshaking [123]. Although human-computer interaction applications would benefit from similar studies, the prominence of such questions in human-robot interaction highlights how the two fields differ in the questions that are significant in understanding and designing for affective tactile encounters. The difference is partly driven by the need to understand tactile interactions with a novel type of partner (in human-robot interactions). This line of questioning is closer to the social science and psychology literature aimed at understanding human-human tactile practices. In contrast to the qualitative and in-the-wild methods used in the area of human-computer interaction, a more quantitative and controlled-study approach is generally taken in this body of work.

In [124], participants conveyed eight emotions to a Nao robot via touch. The paper concluded that female participants conveyed emotions for a longer time, using more varied interaction, and touching more regions on the robot’s body compared to male participants. By instructing the participant to imagine that they had felt these emotions and that they would like the robot to understand how they felt, and touching it in ways that they felt were relevant for conveying each specific emotion. [124] found that the negative conveyed affect (e.g., anger, disgust, fear) were typically more conducive to expressivity than the positive affect (e.g., happiness, gratitude, sympathy). Another study [125] conducted by the same research group, with participants conveying affective experiences to a Nao robot, indicates that users find it significantly easier to convey positive/pro-social affect than negative affect, with love and disgust as two extremes.

The affective experiences in human-robot interaction involve factors beyond touch itself. For instance, in the context of human-robot handshaking [126], additional factors such as gaze, voice, and facial expressions influence the perception of a robotic handshake, while internal factors like personality and mood can also affect the way in which human participants execute handshaking behaviors. A user study conducted in [127] also demonstrated that some tactile gestures are related to the personality traits of participants, such as neuroticism and extroversion, as well as robot attributes such as anthropomorphism and animacy.

A classic group of non-humanoid robots used for behavior study is stuffed animals. For instance, the haptic creature developed by [128] was used to study human intentions and expectations in touch. By embedding custom, low-cost piezoresistive fabric touch sensors, [129] developed an emotionally-aware robot pet with flexible and stretchable tactile sensing at 1-inch taxel resolution. Three user studies with 26, 30, and 20 participants, respectively, were conducted with the robot pet to collect social touch gestures, relieve emotionally intense memories, and evaluate researcher-designed breathing behaviors for emotional content (respectively).
B. Robots Touching Humans

As has been highlighted throughout this survey, touch is of great importance to humans. Studies have demonstrated that bodily contact and tactile perception play a huge role in psycho-emotional and social development with respect to health and mental disorders \[130\]. Furthermore, humans obtain important information from touch during social interactions. This information, combined with other important factors such as the context of the interaction, the emotion, and the beliefs of the other individual, allows for a richer perception of the interaction taking place and appropriate responses to it.

To enable a robot to closely interact with humans and support the psycho-emotional health of humans, as well as to improve the naturalness and intuitiveness of human-robot interaction, it is expected that the robot should understand and convey appropriate information through touch \[131\]. For this reason, a huge amount of research in social robotics has been dedicated to human recognition of and response to artificial emotions \[132\].

1) Technologies for delivering artificial affective touch: Similar to the field of human-computer interaction, the hand has been considered as the primary means for touch in human-robot interaction. The humanoid robotic hand is a key feature when the robot is conveying affective emotion to a human through touch. However, studying and designing for human-robot interaction requires tackling more complex questions and challenges. In general, robotic hands are designed with either linkage-driven finger mechanisms or soft/compliant mechanisms \[133\]. A review on the linkage-driven finger mechanisms of prosthetic hands can be found in \[134\]. Robotic researchers have developed under-actuated and fully actuated mechanisms to mimic the degrees of freedom and compliance of human hands to give robotic structures similar dexterity to that of human hands. In contrast, soft robotic hands combine anthropomorphism with soft materials to achieve human-like dexterity and safe interaction \[101\], \[135\]. Another review on the general development of robotic hands can be found in \[136\].

Apart from humanoid robotic hands, a robot with a haptic rendering surface can also be used to transfer affective experiences, simulating the feeling of being touched. \[137\] developed a silicone pneumatic soft robot to provide affective touch and compared its performance with that of a human hand and a soft brush. User studies with 22 participants, measuring subjective ratings of pleasantness and intensity and electroencephalography (EEG) responses, validated the feasibility of the proposed soft robotic haptic device. \[138\] developed a wearable robot that mimics human affective touch to build social bonds and regulate emotional and cognitive functions. They designed a novel deep learning emotion decoder to identify human affective, non-affective, and neutral experiences. \[139\] developed a soft texture-changing skin with goosebump and spike texture units fabricated using pressurized elastic materials. They fabricated a social robot prototype by combining facial expressions and the texture-changing skin.

2) Human studies on robots touching humans: The effects of robotic touch on humans have been thoroughly investigated through human studies. \[140\], for instance, conducted a study to understand the relationship between emotional valence/arousal and haptic stimulation based on the textures and movements of robots. The researchers implemented tabletop robots equipped with detachable texture modules made of five different materials (plastic resin, aluminum, clay, velcro, and cotton). Thirteen participants were recruited to investigate how they would associate the textures and movements with affective emotions selected from Russell’s circumplex model. The results demonstrated that the robot can express a variety of emotions (e.g., excited, happy, calm, sad). Moreover, the study indicated that the cold texture plays a critical role in expressing negative valence, and the frequency of movements can affect the expression of arousal.

An android robot with a feminine, human-like appearance was used in the study of \[141\] to analyze the effects of touch characteristics on the emotions perceived by humans (strength and naturalness) in human-robot touch interactions. The study focused on the length and type of touch and the body area touched as touch characteristics based on the arousal/valence perspective. It investigated the perceived strength and naturalness of expressions of commonly explored emotions (e.g., happiness, and its counterpart emotion, sadness). The results showed that the length and type of touch are useful in changing the perceived emotions, while the findings on the body area touched deviated from their assumptions. The findings in the study further suggest that a robot can use a brief pat and longer contact by the fingers to better express happy and sad emotions, respectively, when touching a human. Other touch formats, such as hugs, have also been studied. In \[142\], a study was performed with a soft, warm, touch-sensitive PR2 humanoid robot that can hug people and evaluate human responses. The results showed that people significantly prefer soft, warm hugs over hard, cold hugs, and users also prefer hugs that physically squeeze them and release them immediately.

As discussed in Section II, research on interpersonal touch has demonstrated that touch can reduce stress, improve immune functioning, and positively impact human well-being. If a robot can evoke similar effects to human touch when touching humans, the robotic solution could potentially provide support to human health. \[143\] investigated whether physiological, emotional, and behavioural responses induced by robot-initiated touches are similar to those induced by human touches. The results suggest that merely mimicking the human touch action with the limbs of a robot is insufficient and other features, apart from the touch action, are also critical, such as the robot’s touching behaviour, appearance, the user’s personality, the body area where the touch is applied, and the social context of the interaction.

Related research reported in \[90\] surveyed robot-initiated touch in a social context. The survey investigated how the attitude (positive or negative) of the robot and whether the robot touching a person affects how the robot is evaluated as a teammate and a worker. The results indicate that a robot touching a human affects the social appraisals of the robot, although the positive effects of such appraisals were unclear in their study. Findings in other studies, however, show that a robot touching a human can elicit positive emotions and
encourage engagement. [144] conducted an experiment with 48 students in a counseling conversation, in which a humanoid robot (NAO, Softbank Robotics) either touched or did not touch the student’s hand in a non-functional manner during the study. The students mostly reacted by smiling and laughing. The results show that the participants who were touched by the robot complied more frequently with a request posed by the robot during conversation and reported better feelings compared to participants who were not touched.

This section has discussed the research problems and approaches that have driven the work on affective touch in human-robot interaction, highlighting the differences with the human-computer interaction field. In the next section, we will briefly review the work on real-human-virtual-human interaction to identify the nuances of affective touch and the role they play in this space.

V. AFFECTIVE TOUCH IN INTERACTIONS BETWEEN REAL AND VIRTUAL HUMANS

Another important area where affective touch is relevant is in the context of virtual reality, a world of sounds and images where the physical world has disappeared into the background. We can hear the sounds, look at the images, but cannot touch the walls, the objects, the trees and the virtual inhabitants of the world. Still, there are some studies that apply touch technology to enable the avatars or virtual humans to touch the visitors of a virtual environment or to allow the virtual human experience touch. We focus on these in this section.

A. Real Humans Touching Virtual Humans

With respect to the virtual human experiencing touch, [145] explored the development of a virtual skin for their agent placed in a virtual reality environment. Through motion tracking of the hand of a person, the agent can ‘feel’ where a person is touching it and can show some kind of reaction. A similar approach is proposed in [146], where it is paired with haptic feedback to the person. Their preliminary study also provides an interesting experiment investigating the way by which people express certain emotions through touch in such environments. One of the main insights that this study offers is that participants expressed their emotions in more natural ways (e.g., by hugging) than the apparatus allowed as it could only communicate touch through the hands. It exemplifies the typical limitations of the current way used to study touch interactions. The shortcomings of the technology used and the possibilities it offers dictate the range of expressive options and do not take into account how a person would like to interact with the virtual human through touch in a natural way.

B. Virtual Humans Touching Real Humans

The main purpose of introducing touch experiences to the interaction between a virtual and a real human is to enhance affective dimensions in the encounter. In order for a virtual human that has no physical body but is instead made up of sound and graphical images to touch us, they need to become hybrid creatures in between the virtual and robotic. The virtual embodiment needs some kind of real extension, a physical embodiment to make the touch feel felt. When equipped with touch sensors, the same device can also serve as an input device to touch the virtual human ([147]), but as in the work by [145] and [146] one could also use other combinations of techniques. One of the first studies on extending virtual humans with touching devices was aimed at seeing how a gentle squeeze of a user’s hand by a virtual human could express empathy to users in distress [148]. The device used to produce the squeeze in this case was an air bladder. An important outcome of the study was the understanding that touch involves very many parameters and also particularly in a squeeze that not only includes the degree of pressure but also the duration or the number of squeezes and their frequencies. All of these impact the perception of affective valence to a large extent. The context and the purpose of the interactions were also found to be important factors. Context includes the other modalities that are being used to shape the interaction, such as facial expressions and speech prosody. These should act in synchrony.

Other affective haptic modalities have been investigated in the literature, mostly guided by the findings of studies on the purpose and affective effects of touch in human-human interaction. [149], for instance, examined how a simulated social touch by an agent influences the perceived trustworthiness, warmth and politeness of a virtual human. In this study, a participant in the experiment plays either a cooperative or competitive game with two virtual humans. When the game ends, one of the agents approaches the participant and touches the participant on the shoulder. The participant can see the virtual human’s hand and at the same time feels a tactile sensation - a vibration on the shoulder. The study found no differences between the agents touching the participant in either the cooperative and the competitive condition, but in both cases the agent touching the participant was observed to score higher on warmth than the non-touching agent which could be the result of the classical Midas effect.

These studies connect the virtual and the physical environment through physical actuators; an air bladder in the case of [148] and vibration motors in the case of [149]. Others have used other techniques to simulate social touch: thermal feedback [150] and force feedback actuators [30]. It is important to realize that all of these devices are limited in replicating the full dimensions of human touch which involves texture, pressure, temperature and moistness. Therefore, it is important to undertake more design studies on how interaction between a virtual and real human through touch would work ideally. Currently, the studies that have been conducted have been mainly driven by the affordances that the technology offered rather than by the way a person would like to interact with a virtual human in the physical touch dimension.

VI. DISCUSSION

In the previous sections, we have provided an overview of how affective touch has been investigated in various areas of computing. The review has highlighted the variety of
opportunities that technology embedded with some form of affective touch capability can offer as well as some of the key problems addressed and the approaches used. Here, we discuss some of the open research questions that this survey has identified as well as ethical issues that should be considered to inform the design of such technology or for collecting data for building affect or affective touch recognition models.

A. Moving Affective Touch Technology Investigations to Real Settings

One of the main gaps that emerge from our review of the literature across the various areas is the need to understand touch in the wild and in real-world applications. Most of the work on affective touch remains relegated to the lab, focusing mainly on stereotypical tactile patterns and ‘simple’ affective states. Findings from some of the studies reviewed have highlighted the complexity of an affective haptic language as one of the existing barriers.

This is in line with work on other expressive modalities (e.g., facial and body expressions) highlighting that the meaning of any affective sign should be interpreted in the context within which it is displayed and considered together with the other factors that shape that context [32], [151]. The same characteristic of an affective touch (e.g., its temperature or its level of pressure) carries multiple meanings and these are assessed in the moment by considering what is happening, as well as what people know about each other. Physical aspects of the environment (e.g., the temperature) as well as social rules also play an important role as contextual information. [13] showed how the type of relationships (e.g., workers, love partners, friends and family) dictated what was allowed and what was not, as well as how the meaning of the same tactile characteristic changed in different situations. With stronger relationships, i.e. as knowledge about each other is discovered, the expectation of what a person likes or dislikes plays a role in the sender’s use of touch characteristics to build affective meaning.

Contextual factors such as the physical appearance and physical state of the sender or the functional role of the touch may alter the feeling of pleasantness of a slow caress, for instance [152], [153]. This is also the case when we consider robots or virtual humans as the interacting agents, together with their shape and their social role. This is supported by findings in neuroscience (in human-human non-mediated tactile interactions) showing that various factors modulate the feeling perceived when being touched as the tactile stimulation is sent to various brain areas going from lower level processing of sensation to higher level cognitive appraisals [152]. There is also a finer and more dynamic type of context that needs to be considered when investigating affective touch: the underlying affective states of the agents (virtual or artificial) engaged in the tactile encounter. The hesitant or confident gesture of the person reaching out and tenderly touching the other person’s hand adds context to the tenderness of that touch [13]. Indeed, reluctant or relaxed reaction of the receiving hand will further contribute to the development of that tactile exchange. While most studies still consider the design of technology-mediated touch as touch that occurs from a sender to a receiver, in real life these underlying and uncontrolled states shape the interpretation and subsequent tactile interaction. Hence, they need to be considered to fully design for an affective haptic language.

There is also the functional level of touch that is mostly ignored (across the three computing areas). Touch is studied mainly as social or affective and as solely happening with that purpose. However, any touch can be perceived as having some form of affective content. Let us consider the confidence that an expert nurse conveys as she helps a person in pain get dressed. Unfortunately, such real-life use of affective touch remains completely unexplored even if technology may exist for the given application (e.g., a grooming robot). This points to the need for designers of technology for affective touch to consider not only the various contextual factors that shape the use and interpretation of touch but also the multiple levels (often parallel) of transaction that take place in a single instance of (mediated) touch [153].

Another barrier to investigate and understand affective touch technology in the wild is the limited commercial prototypes that embed rich tactile channels. This is also the case for virtual reality technology where haptic feedback is still missing from most commercial applications. From a robotic perspective, the cost as well as the scalability of tactile sensing technology remains a critical barrier. As discussed in [155], the stability and usability of the device are critical for engagement in longitudinal studies. However, the paper suggests that commercial devices even when simplistic do help in-depth investigation in real settings by exposing people to reflect (within real-life contexts and not fictional ones) on what such technology should offer, how and why.

B. Touch is Multimodal and should be Investigated as Such

The survey highlighted how people’s expectations, their use and interpretation of affective touch with or mediated through technology are based on physical affective touch. As such, touch should be considered, investigated and modelled in its multimodality. However, the interaction between modalities is rarely addressed (across the three computing areas) and each modality is generally investigated on its own. In not considering touch’s multimodality, we only have a limited understanding of the richness that tactile interaction can achieve.

The survey has shown that people are open to augmented affective touch. For example, in touch technology, temperature could be leveraged to build nuances of haptic messages based on thermal metaphors (e.g., anger = heat). In physical touch, the temperature of a touch is dictated by the skin of the two interacting humans and people adjusted the temperature of haptic gloves to modulate the valence of an haptic message. The temperature of a robot’s or virtual human’s hands, or even of the surface of an augmented object could similarly be manipulated to add new degrees of freedom to the affective haptic language. Sound has been also identified as an interesting touch modality that is often ignored. While most touches generally only create very subtle sound (e.g., caress versus slap), participants in [13] suggested that sound produced by...
the actuators of their prototypes could be leveraged to provide new ways to modulate arousal and valence. However, what is really missing is studies on interactions with multimodal augmentation of touch.

Finally, touch is also generally considered in isolation as if it happens by itself. In human-human interactions, an exchange of touch generally involves and is driven by the behaviour of the body (e.g., the speed and direction of the arm before patting the shoulder). This driving force when observed helps us to prepare for that tactile encounter. This preparation contributes to shaping expectations and hence the interpretation of its meaning. In the human-computer interaction literature, such aspects remain completely unexplored. In the area of robotics and partially in the context of real-human-virtual-human interaction, the presence of a body may directly lead to different effects on the perception of touch. Sensory-motor coordination is indeed a critical driving question in robotics. However, studies in this direction are still quite limited in affective touch and call for more attention to this extra dimension of touch (movement driving a touch gesture) [154].

C. Technical Challenges

There are various technical challenges that currently limit development of affect-capable technology. Existing challenges can be split into three main areas.

1) Delivering richer and multimodal haptic feedback to the human skin: One important finding emerging from the perspective of haptic feedback is that current devices are still very limited in the type of stimulation that they can deliver to the skin. Vibration is still the most used feedback integrated in haptic devices despite being the most unnatural. In addition, of particular importance is the need for fine-grained modulation of the speed of (de-)activation of the various haptic modalities. This is critical to create a sense of natural touch. For example, the transfer of heat from one skin to another is generally progressive rather than sudden. In addition, as skin sensitiveness differs from person to person, it is critical that haptic feedback are designed to address such differences either when they are driven by computational models or created by humans and delivered through technology. More complex and richer haptic feedback are investigated outside the area of affective touch and could provide new interesting opportunities. For example, [156] proposes a software and hardware toolkit to print on-skin haptic devices. Such devices can be used to produce a variety of skin deformations (stretch, pressure and movement). The emergence and availability of toolkits such [156] could make the use of advanced haptic technology more accessible without the need for expert knowledge. Designers could use such toolkits to explore and program different spatio-temporal dynamics and form of the feedback. Following, Jewitt et al. [157], there is a need to rethink the sensory aspects of digital touch.

2) Building finer touch sensitivity in technology of various forms: As we expect technology, robots and virtual human to perceive our touch and its richness and complexity, there is the need to create finer sensing capabilities. This is particularly of importance in human-robot interaction. Still, it is underdeveloped even in this field. Challenges, identified for human-robot interaction but that can be relevant for the other areas, include challenges:

- related to communication when scaling up to high-resolution and large-area tactile sensors: time synchronization of data, real-time constraints, saturation of the bus;
- with capturing multimodal tactile information;
- around flexibility, softness and stretchability that imitate touch of the human skin;
- on more generalized algorithms and training methods for semantic contact interpretation; and
- with respect to the manufacturing, cost-effectiveness and robustness of the sensing skin.

Another important limitation that cuts across the three application areas is the limited diversity in touch technology morphology. As an emerging field, the diversity of robots as well as technology for affective touch in general is limited. It is essential for the researchers to be aware of the limitations and impact of using specific models of robot and technology shape (e.g., a glove or a hand or a jacket) in user studies. What emerged from our survey, is that the affordances, sensitivity, expectations and social rules that they create do not always generalize to other forms. As such, our understanding of how to design affective touch technology remains limited. There is a need to more comprehensively explore touch across technology forms (and human body areas).

3) There is a need for richer and more realistic datasets: Another critical challenge emerging from the literature is the limited number of datasets available to support both the synthesis and recognition of affective meaning from touch. Even if this review did not aim to be a fully systematic review across disciplines, the 21 datasets shown in Tables [1] and [1] highlight how the study of touch as an affective modality lags behind in comparison to body movement [151] and facial expressions (including datasets for micro facial expressions) [158, 159]. The touch behaviour datasets are also quite limited in terms of size and in terms of type of expressions that they contain given that they have been mostly created in lab settings. Such contexts generally lead to stereotypical expressions that are easier to disambiguate but do not fully reflect the real world. More real-life like data might be collected in spontaneous emotion settings such as games, but again these reflect only specific types of expressions rather than the more subtle everyday affective tactile language. Data in touch datasets have mostly been collected in sessions of limited duration. As such, existing datasets do not fully capture the significant changes in human touch over time and across contexts. For example, typing on a device while standing on a bus or laying down on a bed is very different from typing while seated.

One of the barriers to capturing touch data in real world settings is the difficulty of deploying touch sensors in the wild. Touch sensors practical for everyday use would be a great resource. It is unclear is why there is still very little effort or interest put into this direction. At the moment, touchscreen-based devices are the only scalable touch sensing technology that could enable larger collection of touch patterns in the real word but they have limited applications. For example, touch
experience on a flat screen is very different from touch on a surface that is not rigid, such as our skin, or other more malleable types of material such as textile [160]. Sensors integrated into textile, or sensing skin tattoo may provide a new scalable way to gather such datasets. However, while this may be relevant in human-robot interaction, adding sensors to a material may alter the way the material feels, and since touch is bi-directional, it may alter our tactile behaviour as we engage with such material. If we target how our hand touches, commercial bracelets embedded with electromyography and movement sensors could be used to capture rich description of tactile interaction. However, existing sensors are still limited as they are generally positioned on the arm and do not fully capture all the muscles that reside in the hand. Such bracelets are also prone to noise due to the limited adherence to the skin as people differ in arm size. As such, more work is needed in this direction, especially going beyond capturing only just hands. As robots and virtual humans become pervasive in the real world, they could become human proxies, to create more meaningful datasets.

D. Ethical Issues

A gap in the literature on technology in affective touch interactions is the limited coverage of ethical issues arising from the design or use of interfaces with this affordance. In this section, we highlight a few valuable considerations relevant to the design of affective touch interactive technology. It is worth saying that broader ethical issues that apply to other affective modalities and social AI technology should be considered even in the context of affective touch but they go beyond the scope of this survey.

1) Exclusivity: Much of the technology for affective touch interactions across the three areas is currently centred around hand-based manipulations such as finger swiping or grasping with the hand. The danger here is the exclusion of people who are unable to use their hands for interacting in this way, e.g. amputees, prosthesis users, people with upper limb paralysis. This may be a limitation of the base technology itself, e.g. touchscreens or knobs, rather than of the haptic enhancement. However, this constraint highlights the need for touch interfaces that address the exclusivity of traditional devices. It further has the potential to push the area of affective touch modelling to more interesting directions by bringing machine learning scientists to look beyond applications of touch as a modality of affective expression and instead also investigate it as (part of) an affective experience in itself. An example of a touch experience which can be affective as well being sensorial is the feel of a garment, shoe or prosthesis on one’s body while in motion, e.g. feeling of discomfort arising from hot sensation [161].

2) Privacy, intimacy and abuse: Touch is possibly the most intimate of the affective communication channels as it requires physical contact. Tactile practices are defined by the type of social relationship and acquaintance. A critical issue, especially in technology-mediated human-human interaction is that of how to avoid touch, or how to design for avoiding touch [82], [18]. However, it is not just avoidance that needs to be supported but also the ability to send a message of rejection as we may do through bodily behaviour in human-human interactions when we rebuff and discourage such proximity. Similarly, such aspects need to be explored in interaction with robots or virtual humans given the sense of agency and self that they portray. Touch abuse can further take on other forms beyond unwanted touch. Participants in [21]’s study highlighted the concern of someone else appropriating their own haptic communicating device (their remote hands) and possibly starting to touch or be touched by the partner of the owner of the device. In this study, the device enabled hand-to-hand communication. More critical could be situations in which as in [22], [25], the devices enable touch of more intimate body parts. Such observations highlight the importance of ensuring the possibility of verifying the identities of the communication partners in touch interactions.

3) Reductionism: Reductionism is an issue particularly relevant for affective touch interactions where technology seeks to immerse the user in media portraying real (past) events or experiences, e.g., within a documentary film (see [162] for an in-depth discussion of relevant ethical issues in the context of virtual reality media). With such goals, there can be a tension between bringing the user to feel (and have some stronger sense of) the depicted experience on the one hand and on the other hand unhelpfully minimizing the experience to a pattern of haptic actuation or at best an affective outcome (e.g. a feeling of fear) that does not bear the same implication (e.g. threat to life). While the ethical issues around this are not trivial, one strategy to address them could be for designers to incorporate in the interaction an appropriate distance that helps the user maintain the otherness of the character or event, i.e. being which cannot be fully known or communicated [163], [162]. It is of course fundamental to understand at the earliest stages of design what the specific objectives of the media are and the value that a haptic approach may or may not have to help fulfill them together with the risks it has of undermining valued ends. Further, as is done in other areas of technology design, it may be critical to involve the real factors where possible in the haptic design of such media in order to create a meaningful portrayal.

4) The ethics of automatic affect recognition: As with the automatic recognition of affect from other modalities (e.g., face, body, voice, physiological signals, social interaction information such as phone call patterns), building systems that automatically infer affect from touch behaviour raises critical ethical issues. However, as elements of affective touch technology (sensors, actuators, datasets, uses) are still in their infancy in comparison to these other affective modalities, the issues more specific to touch are still yet to be fully understood. Informed by our review across the three computing areas, we discuss a few relevant issues below:

- **Performance**: First, it is important to consider the assessment and validation of an affect recognition system. As with the other modalities, it is important that researchers and developers make available a full and thorough report of the performance of the system with a clear description of what the system is learning (input and output), the context that it has been trained for, and the dataset(s) used...
in building and evaluating the system. For touch modality where features may strongly depend on the affordance and on the sensitivity of the body area, artificial skin or object surface (of both the sender and receiver), it is critical to further specify components of the touch interaction. Although our review points to current focus on hands or touchscreen (with recognition features being mainly kinematic), we can expect that the complexity of actuators and the level of sensor granularity will lead to a wider set of possible input (e.g., temperature) as the field evolves.

- **Generalizability**: Among the studies explored from the perspective of affective recognition from touch, only a few have explored beyond the traditional generalizability to an unseen subject. Datasets available are still limited and do not allow evaluation of generalizability to unseen contexts (e.g., activities) for example. Findings from studies such as [66] further highlight how touch features may be strongly person dependent due to different body morphologies (e.g., finger size). The generalizability of existing models is additionally limited by the minimal investigation of touch in its multimodality, with most automatic recognition models based only on kinematics and pressure features. Other body of work covered in our review, for instance, show that temperature is a significant dimension of touch used to build affective meaning [13]. Hence, beyond evaluation for generalizability, it is important to also clearly state the dimensions of touch, the apparatus used to initiate and/or capture touch and other critical factors such as body morphology that such generalizability applies to.

- **Datasets**: Beyond arguments already made earlier in the discussion section the need for richer and more realistic datasets, there is additional need for richer annotations. Touch is not just produced but also physically received and this bidirectional manifestation influences both the characteristics of any touch instance and also its meaning. Unfortunately, the current labelling approach fails to consider the dyadic flow in touch interactions such as is done for speech modality for example, only considering human action and not the haptic expression of the technology (or robot or virtual human). As it is important for datasets to be representative, it is critical that the affective touch community re-considers what data need to be captured and what annotations are appropriate.

Further, in the research community, anonymized (or at least pseudonymized) datasets used to build and evaluate the system should further be made available to better understand how representative the datasets used are. This becomes more critical when we deal with data collected in the wild. As the area is less developed than for other expressive modalities, there is also the need for the community to build not only a repository of data but also data collection protocols, to enable in-depth understanding of the data with respect to the capture context because context is critical for understanding behaviour. Sharing of protocols could also foster replication of datasets for new geographical or demographic populations. A similar call has been made in [151] focusing on body movement.

- **Privacy and security**: Privacy is also a significant issue with touch behaviour as with any other affective modality especially when we collect data in sensitive real life contexts. Recognizing affect from such data could further raise privacy concerns and undermine acceptability of touch technology. Further, even if most touch data may not easily give away the identity of the data subject, e.g. as facial images would, existing commercial applications highlight the possibility of using touch behaviour for identification. More critical, for certain touch interactions such as typing, there is the strong risk of capturing (and the misuse of) highly confidential data, e.g. passwords and banking information captured from keystrokes. Users (and research participants) need to be made fully aware of what data are gathered, how they will and could be used, the risks and issues, all in clear and accessible format and language. This is particularly critical as touch is so natural and some easily captured by touch sensors (e.g. based on phone screens) is generally not (yet) salient, unlike for example the lighting up of camera sensors on phones or laptops. Users and participants should also be able to provide (and revoke) consent to the use of their data, with separate consent for the sharing of their data with the community. Researchers and developers must also follow gold standard data protection measures such as encryption and minimization of capture to what is absolutely needed.

Affective touch recognition is still in its infancy but a growing area and hence we are in the right position to discuss and tackle ethical issues (including sociopolitical topics) as we shape the field. This can contribute to proactive combat of misuses that the other affective modalities have faced.

**VII. Conclusions**

In this survey we have reviewed the work on affective touch across three computing areas: human-computer interaction, human-robot interaction and real-human-virtual-human interaction. Beyond being more current, our work complements previous surveys in three ways. First, we took a wider stance on the meaning of affective touch that brings to light other roles of affective touch technology with relevant studies and questions. Second, by reviewing the three areas separately and more comprehensively, we have highlighted differences in questions and epistemologies that drive research on touch in computing, highlighting both common and unique gaps and challenges to be addressed. We hope that by bringing together these communities, this survey will help build synergies across the three areas as the study of affective touch is particularly interdisciplinary. Finally, we concluded by discussing some of the ethical issues to be considered when working on and innovating affective touch technology and when developing automatic affective touch recognition systems.

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