Collaborative Robots and Tangled Passages of Tactile-Affects

Tangled Passages of Tactile-Affects

Barker, NB, Barker [*]

Institute of Education, University College London, edmund.barker@ucl.ac.uk

Carey, CJ, and Jewitt

Institute of Education, University College London, c.jewitt@ucl.ac.uk

Collaborative robots are increasingly entering industrial contexts and workflows. These contexts are not just locations for production, they are vibrant social and sensory environments. For better or for worse their entry brings potential to reorganize established tactile and affective dynamics that encompass production processes. There is still much to be learned about these highly contextual and complex dynamics in HRI research and the design of industrial robotics; common approaches in industrial collaborative robotics are restricted to evaluating 'effective interface design' whereas methods that seek to measure 'affective touch' have limited application to these industrial domains. This paper offers an extended analytical framework and methodological approach to deepen understandings of affect and touch beyond emotional responses to direct human-robot interactions. These distinct contributions are grounded in fieldwork in a glass factory with newly installed collaborative robots. They are illustrated through an ethnographic narrative that traces the emergence and circulation of affect, across *material*, *experiential* and *social* planes. Beyond this single case 'tangled passages of tactile-affects' is offered as novel and valuable concept, that is distinct from the notion of 'affective touch', and holds potential to generate holistic and nuanced understandings of how human experiences can be affected by the introduction of new robots in 'the wild'.

CCS CONCEPTS • Human-centered computing ~ Collaborative and social computing ~ Empirical studies in collaborative and social computing • Human-centered computing ~ Human computer interaction (HCI) ~ HCI theory, concepts and models

Additional Keywords and Phrases: Tactile-Affects, Collaborative Robots, Industrial Robotics, Ethnography, Ethnographic Narrative

ACM Reference Format:

First Author's Name, Initials, and Last Name, Second Author's Name, Initials, and Last Name, and Third Author's Name, Initials, and Last Name. 2018. The Title of the Paper: ACM Conference Proceedings Manuscript Submission Template: This is the subtitle of the paper, this document both explains and embodies the submission format for authors using Word. In Woodstock '18: ACM Symposium on Neural Gaze Detection, June 03–05, 2018, Woodstock, NY. ACM, New York, NY, USA, 10 pages. NOTE: This block will be automatically generated when manuscripts are processed after acceptance.

1 INTRODUCTION

This theoretically orientated paper presents an ethnographic narrative, *Touching Distances*, that was developed from fieldwork at a glass factory where collaborative robots (herein cobots) had been recently installed. The primary function

[*] Place the footnote text for the author (if applicable) here.

of this narrative is to illustrate, and ground, the papers' distinct and original theoretical contributions [1], set against the limitations identified across a series of critical reviews (sections 2 - 4), rather than to detail specific substantive findings which are discussed elsewhere [2], [3]. These cobots (Socabelec's Swabbing Robot) share workspaces and the task of 'swabbing' with workers. Swabbing is a routine and rhythmic part of the production process where the ('blank' and 'finishing') moulds, used to form glass bottles, have traditionally been manually brushed to lubricate them with oil. It is a notoriously hot, smoky, dirty, and potentially dangerous task involving close interactions with powerful machinery and molten glass. These cobots are advertised as making swabbing safer, more consistent and for reducing wastage [4], and are therefore situated within dominant discourses that legitimize robotic advancements on the claim that will free workers from dirty, dull, and dangerous work e.g. [5], [6]. The robotic swabbing systems are customized to the specific equipment and processes of the factory. An overview of a typical workflow is depicted below (Figure 1) and highlights how the nature of collaboration between human and robot can alter depending on a variety of factors.

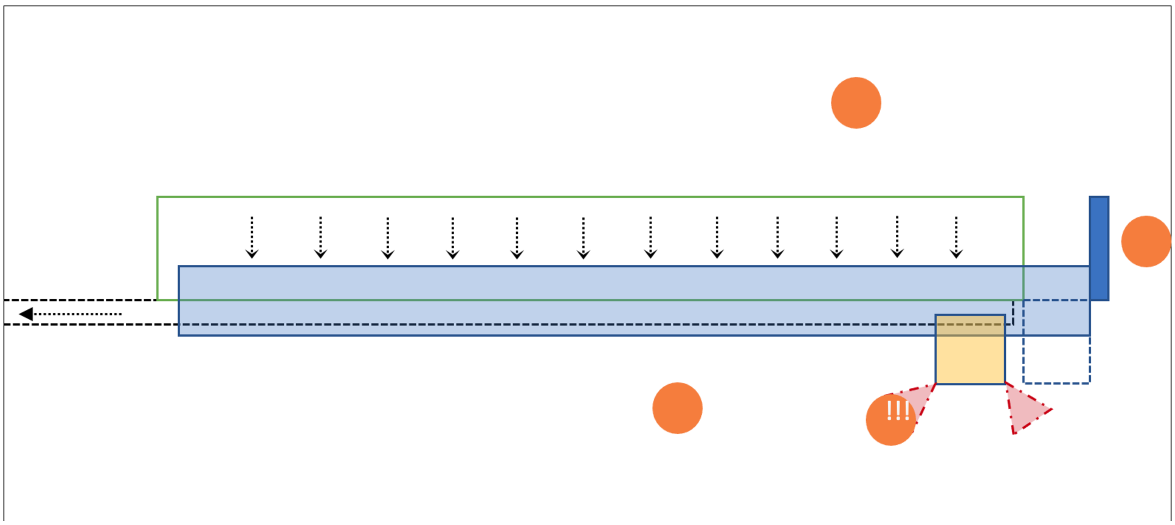

Figure 1: Aerial overview of workflow. Black dashed arrows = direction of glass, coming down from lines off the furnace, into the moulds and then along the conveyor belt. Green box = the machinery that forms the bottles. Opaque blue box = beam that cobot moves along. Solid blue box = control panel. Dashed blue box = caged testing/maintenance area. Yellow box = swabbing robot. Red triangles = proximity sensors. Orange circles = workers.

Molten glass shoots down into moulds at regular spacings across the machinery and timings. At defined intervals, usually every 15 minutes, the cobot will move along the line pausing at each section to swab the 'blank' moulds via spraying oil in a customizable motion[1]. Workers tend to synchronize their schedules so they can simultaneously swab the other side manually whilst that section is temporarily closed from the lines coming off the furnace and opened to allow safe access to the finishing moulds. Workers, however, have a range of duties that differ in degrees of urgency that cannot always be planned for and that are distributed across the team. As such, in the flow of their routine and responsive practices, they may miss scheduled co-swabbing events and return to manually swab the other side later. Alternatively, they may decide to pause, delay, or initiate swabbing alongside the cobot at unscheduled moments. The cobot has proximity sensors and

[1] A specialist configures the specificities of the swabbing cycle at the start of a job change. If it is a reoccurring job, they may decide to choose saved settings, but they can also recalibrate the robotic arm in the caged testing/maintenance area.

will come to a halt if it detects workers or hazards nearby. Workers can therefore continue to access the machines for maintenance and production even when the cobots are in operation. As workers move around their workspaces they try to stay out of range of these sensors; they are also, at times, required to remove objects or dirt that trigger them before restarting the cobot. Therefore, as illustrated, depending on how and when the swabbing is being performed (and other factors) the cobots could be categorized as either 'coexistence' (i.e. no fence but no shared workspace), 'sequential collaboration' (i.e. both human and robot active in workspace but movements are sequential) or 'cooperation' types of collaboration (i.e. robot and worker work on same part at same time) [7].

Whilst these descriptions represented in this ethnographic narrative offer a very particular case, that sets the context for this research, new types of cobots are entering a diverse range of industrial contexts (reviewed in section 2) – and these are expected to fundamentally change the "nature of human-machine interaction" [8, p.20] in industry. This paper makes the case that these transforming contexts are not only locations for production; they are vibrant social and sensory environments and warrant further attention in HRI research and iterative design processes. Consequently, the success of integrating industrial cobots becomes more than a matter of designing for *effective* human-robot interactions but also more broadly in terms understanding and shaping of their *affective* implications. We develop this argument through the following structure. To frame the papers theoretical and methodological contributions, in terms of their scope and value, we begin with three brief review sections that critically unpack: how industrial human-robot collaborations are currently evaluated; how the intimacies between touch, affect, and context are important but often neglected; and finally, how the concept of 'affective touch' (that tends to inform research in social robotics) has limited applicability to such industrial settings because they provide decontextualizes accounts of affect and touch whilst reducing them to emotion. To move beyond these current limitations, we then introduce an extended analytical framework of touch and affect that guided this ethnographic research. This framework is then illustrated through an ethnographic narrative that traces affects as they emerged in, and circulated across, a glass factory where swabbing cobots were recently installed.

Narrative techniques are commonly employed by ethnographers to represent findings and to ground novel theorizations [1], as is the case in this paper. The narrative, Touching Distances, was crafted by combining varied forms of ethnographic data (e.g. interview transcripts, in-situ observations, photographs and researchers' participatory experiences). It is a curated composition of thick descriptions that are intentionally deployed to render more visible how touch is remediated through the introduction of these cobots, across material, experiential, and social planes. In the closing sections we reflect upon the value of the concept of 'tangled passages of tactile-affects' as operationalized through ethnographic research for generating highly contextualized account of industrial cobots 'in the wild'. Here we argue that the contribution this paper makes to expanding the concept of affect in HRI is both timely and needed in a moment where novel and *intimate* collaborations between human and robots are ushered in to mark industry 5.0 [9].

2 DESIGNING AND EVALUATING EFFECTIVE HUMAN-ROBOT COLLABORATIONS IN INDUSTRY

Cobots and collaborative systems have been adopted in a wide range of work contexts including their expanding use for medical procedures and in health care provision. In manufacturing cobots of varied shapes, sizes, and functions are being inserted into a full range of industrial processes and workflows [see 10 for a review]. They are being inserted into mass-production and 'heavy' assembly lines (such as automotive or glass making) as well as in small-scale bespoke and 'light' application (such as UR3s, or 'table-top' cobots, being used in electronics). Likewise, the role of touch interactions with industrial cobots and their use of tactile sensors varies widely. Some cobots make use of tactile feedback in performing tasks [see 11 for a review], others do not; some cobots are reprogrammable through the guiding hand of an operator [10], others are not. Industrial cobotics, therefore, spans diverse landscapes in terms of both application domains and the role of direct touch interactions (between worker and robot or robot and materials). Such diversity heightens the need for contextual 'in the wild' accounts to better understand the implications of specific collaborative configurations. We, and others, have taken a human-centered stance to argue that these accounts should foreground workers' experiences and not evaluate the impact of cobots in relation to improving productivity alone [3], [12]. Current research however is skewed to focus on the latter where studies are ultimately concerned with evaluating the *effectiveness* of interface design for collaborative HRI in Manufacturing.

From this orientation industrial collaborative robotics is a well-researched area [10], [13]–[16]. This literature relies on common methods. Quantifiable metrics have dominated research in industrial collaborative robotics and have been used to study various aspects of interactions and design [see 10]. Here, 'performance indicators' are commonly used to evaluate cobot design in manufacturing and reflect that research and design tend to be "driven from the perspective of productivity and throughput" [14, p.6]. With a view to widen the scope of research in this field Marvel and colleagues [14] constructed an 'evaluation framework' comprising of both quantitative and qualitative metrics. Their qualitative component comprises of surveys designed to capture workers' perceptions of collaboration and interactions, mostly through Likert-scaled questions so they can be tabulated in a quantitative manner. From a human-centered perspective the qualitative dimension of this framework is welcome, but it is also limited. Methods that seek to standardize questions and scales and convert rich qualitative experiences to metrics, tend to yield decontextualized and risk being superficial. Other research employs experimental designs [15]–[17]. These studies also use performance indicators to measure the effectiveness of predetermined aspects of the interface or interaction between human and robot. They also tend to take place in controlled environments where specific human-robot interaction scenarios can be artificially initiated, such as where participants are invited to be hit by the cobot [15]. Performance related data are then triangulated with observational data (e.g. tallies of behavior codes [17]) and survey responses that measure the operators' perceptions (also predominantly employing Likert-scaled questions).

This literature, and these methods, are generating useful knowledge that can be directly leveraged into effective interface design modifications. However key themes for developing industrial cobotics are restricted to dominant topics, such as *safety* (because it is fundamental to humans and robots working in close proximity) [10] and related to this *trust* in being able to safely interact with the cobot [15]. Bogue identified both tactile and proximity sensing, including e-skins, as important research strands in Industrial robotic collaboration because of their potential as safety mechanisms to avoid hazardous collisions [11]. Other projects also examine tactile interactions and haptics for collaborative manufacturing tasks through the lens of ergonomics, also related to safety (e.g. the REMODEL [18] and APRIL [19] projects)**.** To a large extent, the use of tactile sensors in industrial cobots is currently limited to detecting and avoiding human contact rather than for establishing 'responsive collaborations' [7], although these types of collaborations involving tactile sensors do populate the imaginaries of those that are designing the robots for future industries [3]. Other themes attended to in relation to effective interface design are the intuitiveness of task execution with cobots [16], and how much people rely on cobots that have a human-like versus machine-like appearances [17]. However, the reliance on quantitative and qualitative metrics in the field, coupled with a productivity/performance driven notion of effectiveness, does not set out to engage with and therefore neglects the complexities of how workers' experiences are affected by the introduction of novel technologies. To shift focus from the effective to the affective we suggest socially orientated, historical, and ethnographic research is needed to reveal the intimacies between touch, affect and context, work that is reviewed in the following section.

3 TOUCH, AFFECT, AND CONTEXT IN INDUSTRIAL HRI: INTIMACIES AND DISLOCATIONS

Touch matters in industry and human-robot collaborations. It is a resource through which production occurs irrespective of the composition of manual and automated methods that are employed in any given industrial context. Production processes sequence the touching of materials (re)molding matter into desired objects. Whether the productive touch of humans, tools, machines and robots are performed in collaboration or in isolation, they are harnessed toward industrial outputs. Touch also matters as a *social* resource in industrial contexts providing a means of communication between co-workers (human and robotic). Furthermore, touch encounters affect workers' *sensory* experiences as their bodies come into, and out of, contact with various materialities. The intimacies of touch and embodiment within the material, social, and experiential conditions of labour have been mapped by cultural historians that attune their analysis to the sensory character of work, e.g. [20], [21]. Reviewing such scholarship uncovers 'tactile histories' of technologies in industry (for a detailed review of glass manufacturing see [2]). Contemporary ethnographies have added to these intimate accounts by revealing how affective dynamics, of dirty and dangerous manual work for example, can be remediated when novel technologies are introduced into established industrial operations, e.g. [2], [22], [23].

As noted earlier, with a focus on effective interface design (including the use of tactile sensors and haptics) touch as a social and sensory resource has been neglected by empirical research in industrial HRI. One consequence of this is that its significance for affect has not been brought into focus. Where work in industrial robotics has attended to affect they have done so through themes of acceptance/resistance to understand how collaborative technological developments and integrations affect the workforce [12], [15], [24], [25]. These empirical studies usefully raise issues of trust between cobot and worker [15], [24], the importance of the 'social acceptance' of robots in industry (in reducing perceived robot-induced stress during coexistence), and have generated 'integration considerations' that aim to reduce negative work attributes and improve technological adoption [12]. While some of these studies incorporate qualitative elements (e.g. worker interviews [12], [24]) and bring 'context-related factors' into the data collection/analysis, they do not consider the role of touch. Other studies seek to measure workers' acceptance of cobots through Likert-scale questionnaires [15] and through neurobiological proxies of 'emotional affects' such as heart rate and electromyography signals [25]. In both cases, the tactile dynamics of affect in these industrial settings remain unexplored, while current theory and methods rely on talk-based methods that are only partially contextualized.

Dislocating embodied workers and their touch from the affective ecologies of industrial sites of labour and narrowing notions of affect to emotions within industrial robotics is problematic when considering anticipations of an accelerated demand for, and development of, industrial cobots [7], [26]. Not least because of the potentials of collaborative technologies to disrupt traditional industrial organizations where robots have typically been caged and separated from human workers, limiting and highly regulating direct (or close) touch interactions, which shapes affect. Cobots, as one strand of the new generation of industrial robots [26], may, we argue come to signal a transformative moment in the social, sensory, and tactile character of traditionally manual occupations. A need to target the intimacies between touch and affect is emphasized through a broader understanding of 'the social' where industrial contexts are recognized as socially vibrant and affective regions and where industrial cobots are understood as being able to affect the social, sensory, and material contexts of production.

4 AFFECTIVE TOUCH IN HRI

The role of 'affective touch' within HRI has largely been restricted to the domain of social robotics [27]–[32], with particular focus on understanding the affect of direct touch interactions with humanoid or zoomorphic robots. This section gives a brief critical overview of the dominant conceptual relations between affective touch and context within HRI. As will be unpacked, dominant methods seek to capture and quantify humans' emotional responses to tactile interaction with a robot in a range of scenarios and with differing emphasis. Likert-scale questionnaires seek to measure participants emotional responses to particular types of touches with specific robots, e.g. [28]–[30]. Research has also focused on the robot's ability to recognize the communicative and emotional content of tactile gestures in order to develop systems that are able to respond according to humans' social touches, e.g. [27], [33]. Haptic technologies offer yet another route to tactile human-robot interaction where "understanding and creating affective haptics will be essential for social robots" [34, p.3]. The majority of such studies frame affective touch as the transmission of emotion through direct physical contact between human and robot. That is, they hold common the notion of an 'affective contact point', a physical connection that creates a bridge across which emotion can pass.

We suggest a set of theoretical influences and methodological convergences orientate social HRI research towards affect, touch and context in relatively homogenous and focused ways. Working concepts originating from social psychology and neurobiology inform an overarching project in HRI to replicate or harness the affective (or emotional) potencies and potentials of human-to-human touch interactions through advances in (social) robotics. Here affective touch is approximated as "touch that communicates or evokes emotion" [30, p.165]. In a further reduction of touch to psychological affects (emotions) other studies attempt to measure the neurobiological responses of touching and being touched by a machine [35]. Affective touch on this level is partly accounted for through elevations or dips in Oxytocin and other biophysical proxies for emotion that occur during the processing of touch stimuli. The concepts and methods that underpin such quantified classifications of types of touch and their emotional affect only accounts for the 'immediate interaction frame' in social HRI. The epistemological foundations of affective touch in this domain therefore requires highly controlled and standardized research environment. Figure 1 illustrates these points further.

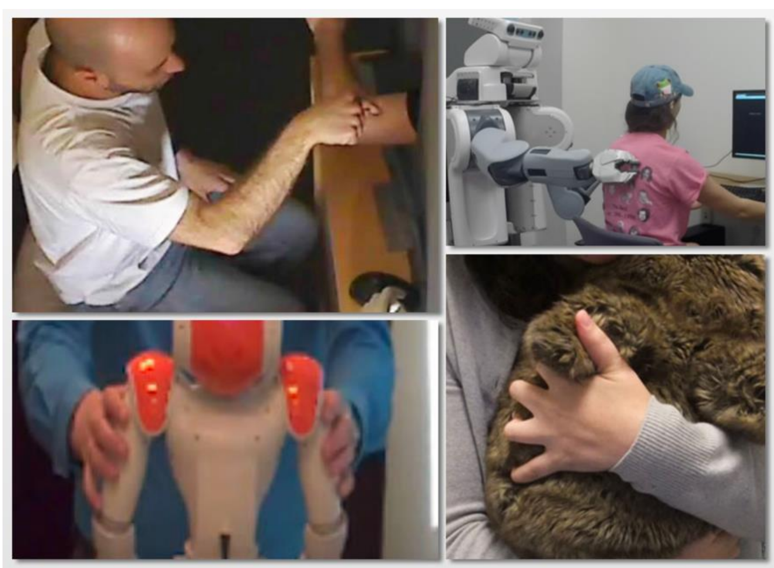

Figure 2: images of participants engaging in human-robot touch interactions from selected studies. Top left [33]: human touches artificial skin to communicate social messages and emotions for the robot to recognize. Top right [28]: robot touches human along with differing verbal cues and participant-observers evaluate robots 'social performance'. Bottom left [27]: participant touches robot on arms

“to convey a particular emotion” (p.476). Bottom right [30]: participant cradles robot as touch gesture profiles are recorded as well as participants emotional responses to these interactions.

These methods are productive in arriving at tangible emotional affects when physical contact between human–robot is observed, however, conducted under lab conditions (i.e. in artificial settings and scenarios), they are critiqued for decontextualizing touch. Methods therefore render the social and sensorial complexities of touch in order to quantify and topologize its (emotional) affects. These studies position contextual factors as ‘cautionary markers’ [28] that frame emotional responses with respect to tactile human-robot interaction. They are, however, limited by the number and nature of contextual factors that can reasonably be accommodated as variables. The concept of affective touch and its associated methods have not, therefore, yet been brought into a theory of affect and touch that “extends beyond a single human and a single robot” [36, p.3] engaged in a direct touch interaction.

There is growing interest in the HRI community to extend theories and methods to trace the affects of touch beyond the lab into domesticated and social habitats. The importance of understanding how robots become social and affective agents in the workplace (such as industrial contexts) is reinforced through recent qualitative research that identifies ‘ripple effects’ across the social environment when a robot is introduced [36]. Elsewhere the importance of better understanding embodied emotional activities and interactions in ‘non-social’ as well as ‘social’ environments gains traction [37]. While this appetite grows in the field there remains a realization that “we have a limited understanding of how people will respond to robots in complex social settings and how robots will affect social dynamics in situ” [36, p.1]. This paper builds on this interest, bringing a critically informed desire to broaden HRI approaches to affect, to set out an alternative path to engage with the complexities of touch and affect.

5 RESEARCH DESIGN AND METHODOLOGY

The research design uses ethnographic fieldwork across multiple industrial contexts to produce thick descriptions of how novel robotic technologies can remediate the dynamics of touch as situated in the social and sensory contexts of labour in the ‘real world’ (see [2], [3], [38], [39] for details on the methodological framing). In this theoretically orientated paper, we offer an ethnographic narrative derived from one site where a cobot had been recently introduced to assist with the task of ‘swabbing’ in a glass factory. As noted earlier, the primary function of this narrative is to illustrate, and ground, the papers’ distinct and original theoretical contributions [1], set against the limitations identified across the critical reviews above (sections 2 - 4). It is therefore beyond the scope of this article to detail specific substantive findings – and these are discussed elsewhere [2], [3]. Consequently, the ethnographic narrative elaborates on themes sparsely. Data were selected to indicate the utility of the framework, for informing iterative design processes from a human-centered perspective, rather than to evidence phenomena leading to concrete recommendations.

The field researcher spent a working week at the glass factory. In the Factory, being in touching distance of the machines is required for many tasks, including routine swabbing the moulds (applying oil to stop the glass sticking), a job that workers now share with a cobot (see Figure 1). This has the effect that the workers’ day-to-day touch practices and positioning was altered. During fieldwork the first author shadowed two manual workers (Dave and Lee – all names are pseudonymised), observed working practices, and interviewed workers, management and office staff. The purpose of shadowing workers, where possible, was based on a strategy to become a ‘tactile apprentice’ (refining Pink’s ‘sensory apprentice’ model [1]) to learn about and through touch in that industrial context. The principles that guide sensory ethnography align with a felt phenomenology [40] and phenomenologies of embodiment as orientated within affect theory [41]. This methodological approach was selected for its potential for producing contextually rich and dynamic descriptions of touch [38], gaining fresh insight for how affective ecologies become remediated through the presence of cobots 'in the wild'.

Data was collected using fieldnotes, and recordings (by video and audio), with selected interviews transcribed (n = 5). The background noise in the Factory and the often-informal character of conversations with informants meant recording was not always possible, in these cases, fieldnotes were relied on. The data collection was accompanied by an analytical process that expanded our focus to "other qualitative factors such as the feeling of proximity or distance that accompanies touch experience" [40, p.155]. The data collection and analytical processes were guided by an extended and contextualized view of affect and touch (introduced later).

The value of this approach is that workers' experiences take the foreground and are contextualized within the material and social dynamics of that industrial setting. Zooming in on a highly contextualized case limits this papers' scope in terms of providing general design recommendation for the integration of collaborative robots in industry, a domain that varies greatly in terms of type, scale, function, and social/sensory context etc. (see section 2). Nonetheless, the narrative we present serves to vividly illustrate how these cobots reorganized established tactile and affective dynamics in dispersed rather than direct ways. Consequently, the main contribution of this paper is a theoretical framework and methodological approach, that we introduce now.

6 ANALYTICAL FRAMEWORK: TOWARDS AN EXTENDED AND CONTEXTUALISED VIEW OF AFFECT AND TOUCH

Through the analysis we sought to navigate the complexities of, and intimacies between touch, affect, and context by drawing on affect theory [41], felt phenomenology [40] and a 'socially orientated' stance to touch [42]. More specifically we traced these relationships across *material*, *sensory* and *social* planes of analysis. In this section we present the concept of 'tangled passages of tactile-affects', and offer an alternative framework equipped to trace affects through touch in ways that respond to the challenges raised in relation to dominant HRI theories and methods.

Our first step towards gaining an extended and contextualized view of affect and touch was to reach beyond emotional responses. Theoreticians have sought to disrupt the synergy between affect and emotion arguing that it does not fully capture the diversity of affects that may pass between bodies or between human and robot. In technology focused theoretical work Ash proposed that "[affect is a] force that has the capacity to transform the corporeal and material basis of the human body in ways that are not reducible to a subject's emotional state" [43, p.85] and Paterson understands that affective ecologies are "irreducible to individual emotional states" [40, p.166]. Beyond emotion, affects are represented in this paper as material, experiential (sensory), and social. Whilst acknowledging the valuable knowledge generated through the dominance of affect-as-emotion in HRI research, we have argued that "contributions have yet to consider the sociality of robotic touch (in the broadest sense) in the 'real world'" [38, p.128].

This statement indicates our socially orientated stance to digital touch [42] where social and affective associations emerge through a myriad of interactions between humans and non-humans in these industrial settings. The complex and contextualized nature of the sociality of touch forms a position that resists quantification (including 'qualitative metrics') and the universal classification of social and affective touches (i.e. associating types of touch with defined emotional responses). Rather, the extended view of touch that we promote foregrounds the "social, sensory and material environments" [42, p.130] where touch unfolds, a lens that we have applied to a range of technological areas including haptics in immersive VR [44], [45]. Our analytical framework, that rests on an extended conceptualization of touch, emerges from a sensitivity to a range of encounters between bodies–technologies–environments and is pursued through investigative dimensions that span across material and social planes (see fig. 3).

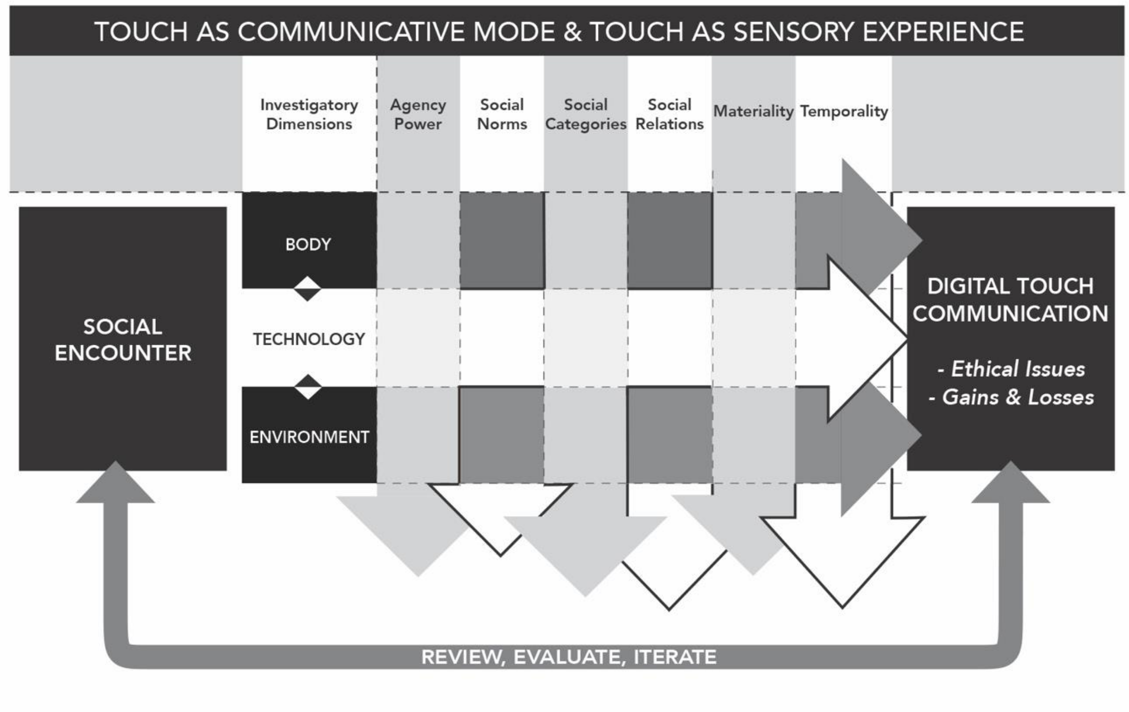

Figure 3: Initial InTouch research and design framework for digital touch communication (from [42, p.129])

Attention to affect can be located through both axes of this framework. Affects pass between body-technology-environment in the vertical and these are stretched across the horizontal as the material and social dimensions of touch are investigated. To elaborate on this analytical approach, that guided this research, we extend this stance to explicitly speak to the intimacy between touch and affect. This was progressed by turning to theories of affect [41] and emphasize a felt phenomenology [40] to consider the complex and contextual relationships between touch and affect.

In the broadest sense affects are found in "those intensities that pass from body to body (both human, nonhuman, part-body, and otherwise)" [41, p.1]. Such affects do not necessarily take direct paths between bodies, for example, human and robot. Rather they often circulate and travel between bodies-technologies-environment taking indirect routes in ways that disperse affects across time and space [41]. A felt phenomenology centers the body and the workers' experiences within this nexus. It provides an analytical approach directed at a sensory plane from which to trace the "exchange of affects between bodies" [40, p.147], technologies, and environments. Moreover, an analysis of workers' experiences through a felt phenomenology extended our descriptions of touch to the proximities associated with being in (and out of) touching distances. Consequently, an extended view of touch and our analytical framework make the case for tracing the mediation of tactile-affective ecologies beyond localized, bounded, and static (touch) encounters between human and robot. That is, touch remains implicated and in play even when it is not directly physically present.

A qualitative analysis of the ethnographic data was initially structured through analytical concepts that: (1) stretched the notion of tactility across time and space (tactile landscapes); and (2) recognized that touch (as a social and sensory resource) is not static but rather shaped and reshaped through participants' ongoing engagement with their settings (touch trajectories) – both concepts are discussed in detail in [2] and return through the discussion that accompanies the ethnographic narrative. These concepts, align with our extended view of touch, and framed our initial analysis exposing themes of intensities-proximities-durations, intimate relationship between the sensory and social, and the dispersed technological mediation of touch. Following preliminary analysis, the corpus of data was reviewed with attention given to illuminate affect and touch (as outlined above).

The output of this process was the crafting of an ethnographic narrative that traces the tangled passages of tactile-affects across *material*, *sensory* and *social* planes. With little direct human-robot touch interaction, themes of proximity and the sensory implications of being in (or out of) touching distances became prominent to understand affect. The ethnographic narrative, *Touching Distances*, offers a vehicle through which to illustrate how we operationalized a tangled theory of tactile-affects during the fieldwork and writeup of the ethnography. The narrative shows the vibrancy of the social and sensory environment that encompasses this production process whilst demonstrating that there is more to affect than the (touch) interaction. The narrative is composed of various ethnographic encounters (e.g. drawing on conversations with and observations of informants) and responds to Paterson's contention that affective textual formats (e.g. texts that use strategies such as tactile metaphors, narrative, and poetics) are best suited to illustrate the complexities of touch [40] and novel theory [1].

7 AN ETHNOGRAPHIC NARRATIVE: TOUCHING DISTANCES

The ethnographic narrative traces the (material, sensory and social) affects that accompany being in touching distances of molten glass and powerful machines in a glass factory. To be in touching distance in this industrial setting is to be affected by heat, noise, smoke and the prospects of danger. The narrative is punctuated to highlight the mediating effects that the introduction of swabbing cobots had on the contextual dynamics through which tactile-affects emerged and circulated. The three fragments of *Touching Distances*, each presented below, foreground different analytical planes (without completely untangling the intimate flows across them) to facilitate the elaboration of key themes. The first text elevates the *materialities* of the context where direct touches are regulated and mediated through both technologies and techniques that distance the workers' bodies from hot and potentially dangerous physical contacts. The second traces these material affects into the *experiences* of workers, bringing the themes of positioning and proximities into dialogue with durations and intensities. Third, a non-exhaustive selection of the *social* reverberations is expressed to further illustrate the en*tanglement* of tactile-affects. Selected examples show how the social feeds back into the material and experiential dimensions of the context. Together, these (con)textual and textured interludes trace tactile-affects in-situ, where the intimacies of affect and touch are exposed, as are some of the important implications of introducing this cobot into the wild.

> *Touching Distances: can't touch this*. Four glowing gobs (teardrop shaped slugs of molten glass) fire off one section of the line into the moulds every few seconds. Between each cycle the heavy and powerful machinery clamps tight, shoots air into the glass filled moulds at pressure transfers these bottles to other side of the machinery for refined shaping. The newly formed glowing objects are then placed onto the conveyor belt. These bottles join with numerous sets of four from closely neighboring sections of machinery.
>
> Approaching the appositely named *hot end* from a distance this visual spectacle is accompanied by a gradual intensification of heat, noises, and aromas. The gradient of the material sensorium tangles with an appreciation of the power of the industrial process and the potential of harm by coming into contact with certain parts of the machinery and materials. Unsurprisingly touch appears to be highly regulated, meticulously practiced, and specialized in this industrial context.

When expressing intentions to become a 'tactile apprentice', to learn about and through touch, the operations manager clarified that I must not touch any of the machines or heated glass. Instead, he instructed Dave and Lee to facilitate as many (safe) hands-on experiences as possible and to demonstrate physical interactions with machinery such as swabbing as requested. Even employed apprentices must complete 12 weeks of academy training where they practice touch safely on replica machines and in virtual reality before moving to the 'shop floor', under strict supervision. Even when skilled and safe, workers never directly touch the machines or hot glass. Touch interactions are always mediated through technologies (e.g. heat resistant gloves, tongs, and swabbing brushes) and regulated through defined and practiced tactual engagements. Techniques and technologies distance the body from the material affects of heat and potential harm.

Figure 4: Tools to handle the heat. Heat resistant gloves (top left), metal tongs (bottom left) and swabbing brush (right)

In this context potentially harmful touches are mediated through primitive technologies (fig. 4) that maintain distance between bodies and hot/powerful materials. Dangerous touches are regulated, limited and practiced so that minimal distances are enforced (by creating barriers (e.g. gloves) or extending the tactile body (e.g. swabbing brush and tongs)) because the production process has clear potential to materially affect (or damage) workers' fleshy bodies. The swabbing cobot injects yet another mediating technology that aims to create distance between workers' bodies and the machinery. This aim of the cobot is supported through one of the key justifications given for investing in technology, "one of the biggest accident-related tasks in the hot end is swabbing. So first of all, we needed to find another way of swabbing" (operations manager). The company selected the cobot as their best current solution for making swabbing safer, and more efficient. Safety concerns were partly alleviated because (1) it outsources part of the job (thereby reducing number of potentially dangerous touch encounters) and (2) because it repositions workers while the machines are being swabbed so that they can move to locations where they can observe and respond appropriately to problems that can occur,

> "The problem is, if you are around the back of the machine swabbing… there is no-one around the front watching the machine… At least now when the robot is swabbing they [the workers] can view what's happening after the swab. So if there is a swab related issue they can see it… They don't have to run around and sort it out" (operations manager)

Creating distance between bodies and the material intensities of the production process through a range of technologies (primitive and novel) serves a dual purpose; to prevent (or minimize) risk of direct contacts between bodies and hot/powerful materials and to reposition workers to give them time and space away from the machines and "see the bigger picture". Therefore, these mediating effects of the cobot reorganize material proximities in both close quarters (reducing manual swabbing) and in more distal ways (repositioning bodies). Tracing these mediations across a sensory plane, as materialties pass through workers' experiences, there is a remapping of exposure to, and absorption of, felt sensory intensities (e.g. heat-noise-smoke). The sensory dynamics of touching distances are fleshed out below.

Touching Distances: from the fire into the smoke. "You get used to it" proclaimed Lee wiping beads of sweat from his forehead after a 30-minute stint of pulling bottles off the line (a manual intervention to prevent machine jams) alongside colleagues joining from other lines to assist. He continues to describe how exposure to high heats are "all part of the job", but also reels of examples of when the radiating affects, that are first forged in the fires of the kiln, flow through to his experiences where the heat and task ahead become more 'testing' and 'daunting': "some days you might spend hours stuck in the machines, that can be hard"; "during the summer it can be much worse, the heat is more intense". Swabbing the machine involves coating the hot moulds with oil and plumes of smoke are created, this adds a thickness to the intensity of the sensory input while in touching distance (fig. 5). Such examples bring a rubric of durations–proximities–intensities into focus.

When possible, respite is sought away from machines and in air-conditioned spaces such as the 'refuge rooms' where conversations can occur (noise levels close to the machines make it difficult to communicate beyond gestures and touch). Even when not directly attending to the mechanical coalface and free to move into cooler-quieter-cleaner areas workers are never fully dislocated from the outside intensities. Participants noted that during the summer these spaces can be compromised and "overheat" to an extent where the control computers located in them can become temperamental (according to Dave).

Figure 5: Manual and robotic swabbers in smoke

With durations–proximities–intensities in constant flux depending on a variety of factors the material thresholds that experienced workers might "get used to" can be pushed close to their boundaries or exceeded. For Lee the sensory experiences of his labour were constitutive of a "testing environment" that could be exampled through times where the heat of the work bordered on being too intense, too close, and lasting for too long – with little refuge.

As narrated, workers' experiences were relational to durations-proximities-intensities and that exposure to these dynamics "can reorganize the material thresholds of the body" [43, p.88]. Whilst Lee articulated getting "used to it", our analysis recognized that material affects do not always uniformly pass onto embodied experiences. Elsewhere we have articulated and empirically detailed these as 'touch trajectories', comprising of both commonalities and variations. There are general social and sensorial processes within the glass factory where workers learn to 'handle the heat' and understand their 'limits' of being close to intensities such as heat-smoke-noise. Whilst expanding on substantive themes lies outside the scope of this paper, as it is primarily concerned with articulating and contributing a novel theory and methods, it is worth noting that all three analytical planes of our extended framework (material, sensory and social) came into play in learning to handle the heat. For example, degrees of sensory desensitization occurred through accumulated exposures to hot materials and was simultaneously framed by social exchanges between workers [see 2].

Beyond gaining a richer understanding of the complex affective dynamics of these touch trajectories, variations in workers' 'material thresholds' were understood to impact the effectiveness of other technologies that were trialed before the cobot was introduced. For example, a notable draw back of the 'swabbing gun' (a handheld device that sprays oil onto the machine with 'increased standardization' than manual swabbing techniques) was that "some people can stand closer because they can take the heat, others can't. So you're not getting a true reading of if it is working or not" (Dave). We argue that through ethnographic immersion researchers encounter their context in a dynamic and nuanced way, that in this case revealed how the passages of tactile-affect are mediated through the introduction of new technologies in ways that were not restricted to the direct human-robot (touch) interactions. The approach, therefore, offers an expanded view not accommodated by the notion of 'affective touch' and its associated methods (section 4). Furthermore, as the example of learning to handle the heat relates to a variety of factors (e.g. training, workplace culture, gendered touch expectations, technologies, production processes) we posit that holistic and contextual accounts are useful because they can, in turn, feed into iterative design processes where possible *negative affects* for workers may be identified and addressed. We return to this argument in our closing remarks (section 8).

We now home in on the affective passages of smoke in this context as a thick illustrative example of how touching distances can, through sensory experiences, begin to evoke socially rich themes as encapsulated in the conversations below.

> 05/02/20: **Barry**: "anything that gets your body away from the heat, and the machinery, and the smoke is good"
> 06/02/20: **Dave**: "Like Barry said to you yesterday, the smoke from swabbing, if you are doing that every 20 minutes it's a lot of smoke that you are breathing in"
> **Lee**: "they don't actually know what that smoke is doing to people, whether it is good, whether it is bad, whether it is just normal"
> **Dave**: "I know in [another factory] they had someone do a breath test thing at the start of a shift and at the end of the shift and it is as if you have smoked like, I can't remember the figure but it's like a pack of cigarettes a day from just swabbing a machine"

Tracing the thick material intensities of smoke plumes through the sensory reveals here how the sensory is intimately tied to the social as stories about smoke circulate within the context. The stories encountered during fieldwork were clouded in speculation and spoke to the workers' felt experiences; they were important aspects of the vibrant social dynamics of this industrial context and yet pervade being captured through qualitative metrics and common methods in HRI (see sections 2-4). Workers offered no 'definitive' answers on the material affects of smoke on their bodies, however through many conversations workers spoke of the positive impacts that the cobots have made to the sensory conditions of their labour. Barry, in particular, spoke of how the smoke (and heat) affected his energy levels and life outside of work, and he welcomed new technologies that distanced his body from the smoke on the grounds that he wanted to be "healthier for his family". In contrast, one worker had a theory that they rarely got it ill or caught colds off their family because the "heat kills the bacteria". The point here is not the medical truths behind these perspectives but that a circulating ecology of stories emerges in-situ, diversely so, in ways that interact with the entry of new technologies into the material and sensory dynamics of labour. Being in position to encounter the various stories that are told, where they are told, provides useful information on whether and *why* a technology is been accepted, or rejected. From a human-centered perspective our analysis identified which stories were dominant because they were common or retold in different circles (e.g. management, workers, communications department). In this case workers recited generally positive messages associated with the cobot, and these stretched beyond well-trod themes of health and safety (see section 2), such as to workers' experiences of rhythm and pace. When the cobots were introduction workers "were going it's too fast, it's too fast. Nothing is said now because they have all got used to it. They have realized they can do it and the faster they do it the faster they can step away from the heat and smoke" (Dave).

Throughout the ethnographic narrative we have traced the material through to workers' experiences and in doing so the social has been intimately evoked in a myriad of ways. This theoretical point, that the social is tangled through both the sensory and material dynamics of the context, is illustrated further through the narrative section below.

Touching Distances: social reverberations. When a part in the machine needs to be changed a worker stands on the machine and leans into it whilst another directs an 'airline' at their feet to delay or dampen the build-up of heat in their boots (fig. 6). The joint practice aims to slow down the passage of heat from the metal, through their thick soles, and to stop a breaching of thresholds. This collaboration is important as Dave realized when changing parts without a colleague cooling his feet "you could stand up there and think I feel a bit of heat coming through I will be alright for another 2/3 minutes and then you get off when it starts burning [Lee interrupts - your foot is melting] and then it starts burning more and more… by the time it takes you to walk to a chair and take your boots off you have gone through the pain".

Other displays of teamwork and camaraderie (including laughing and smiling at each other, patting on the shoulder and exaggerated gestures) feature with regularity at times when groups attend to the machines for a prolonged period of time (e.g. pulling bottles of the line that happens when consistent defaults occur and settings are being adjusted to remedy these). The "testing environment" is a backdrop to the observed social dynamics.

The testing environment, that is stoked when in touching distance and contingent with durations and intensities, also underpins 'flareups' between workers. The physical manifestations of heat stress are explained and warned against our noticeboards around the site, including self-diagnosis advice of dehydration based on urine colour. The experience of feeling stressed by the heat is discussed by workers as being a catalyst for social tensions, "you can have a big argument with someone, and then at the end of the day it is forgotten about. You both know it was the heat" (Dave).

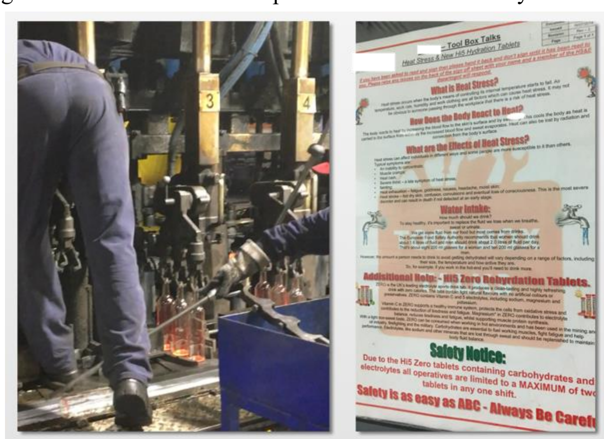

Figure 6: coworker spraying air into Dave's boots while changing a part in the machine (left); poster of heat stress (right)

The "testing environment" is not solely a sensory statement or a recognition that in certain areas "it's just stifling. There is no air" (Dave), it is also a socially active statement insofar as the environment affects social dynamics (e.g. arguments) as well as social practices having an affect on the environment (e.g. spraying air into boots). The former, a directional flow from material-to-social, is evidenced through observed camaraderie in the face of prolonged periods of attending to the machines or through 'in-jokes', such as "we have a joke because people come for a visit and then go so don't see what it is like. It is a hard job; we say 'they think we make biscuits'" (operations manager). The later, a directional flow from social-to-material can be evidenced through the following example.

"When we first got them [the cobots] we put signs up saying don't leave anything out at the back of the machine. It has to be clear. Now it's just second nature, keep everything out of the way because the robot is going to go at

> some point. If that arm comes out and touches anything it trips itself out. But I remember at the start constantly running around checking. But now it's like everybody has got the rhythm of them, they are used to them" (Dave)

Workers spoke of changing their practices and environment to accommodate their new coworker (i.e. the cobot), these alterations were made to ensure that the cobots sensors were not triggered by objects in a shared workspace. And because the cobot supports them with the once entirely manual job of swabbing, the workers appeared motivated to remove objects that the cobots would sense and be affected by. Workers therefore became aware of and concerned for touching distances relational to their robotic coworkers. Together these examples explicitly illustrate the multi-directionality of the affective *reverberations* across material, sensory and social planes. They serve to illustrate that, 'in the wild', tactile-affects stretch far beyond any direct human–robot interaction, and that this may have implications for iterative design processes that in turn should also reach beyond an analysis of the effectiveness of an interface.

The swabbing cobots are embedded within the sociality of the working environment that has many dynamic facets; their role, value, and cost cannot be evaluated on productivity/performance indicators alone. This stated, their value in terms of production, specifically weight/cost of glass wasted that the cobots are estimated to save is visually displayed in communal spaces. These printouts were referred to in observed discussions between workers, informing their perceptions. Whilst workers did not disregard the quantifiable performance indicators that they were presented with, more relevant to them was that sharing swabbing with cobot had noticeable experiential affects. And as such they now complain if they are out of action, asking for them to be fixed as soon as possible because it makes their job easier (operations manager). Therefore, such insights extend iterative design conversations to recognize the importance of cobot reliability (or minimizing fixing-times or setting up contingencies) so that their operation can fade into the background of workers' experiences and not become a source of dissatisfaction nor complaint. They also suggest the importance of considering what might be important to communicate (e.g. safety, experiences, productivity), how (e.g. notice boards, training, champions) and to track whether this is having a positive overall affect from the workers' perspective.

The aim of better understanding these affective dynamics (between material, sensory and social as mediated by new technologies) would not be to arrive at a point where *every* worker is positively affected in *any* conceivable way. Of course, this would not be realistic as workers are individuals, with differing tastes, routines, material thresholds and so on. For example, some are disposed to positively welcome their presence, like Dave, "I love it… I like technology anyway so when they were coming I thought 'we can make this work'" (06/02/2020) and when his results consistently improved making him 'look good' these *affect*ions were confounded naming 'her' Deborah. Reflecting on his relation to technology, Dave also noted that others started from a less welcoming position. Given the individualized nature of workers' experience the purpose of our framework then is generate both a holistic and nuanced sense of what aspects of the working environment may be negatively affecting workers, as they *emerge* in relation to the introduction of novel robotic systems. These sensitivities challenge iterative design processes to open up and consider areas, that are specific to that context, and that may not necessarily be focused on (or addressed) in current HRI or industrial robotics literature. They may also stretch familiar topics, such as human-cobot *trust*, towards different influencing factors.

Issues of trust were identified and cautiously navigated; these extended beyond its dominant relation to safety. It was the case that workers talked about having to get used to sharing the same working environment, to feel confident that the cobot won't hit into them. Moreover, that "you have to put your trust in the robot that it is working right. Because that stops the section for you to go and swab it. Even though you've got a long stick, you don't want to get your swab stuck" (Lee, 06/02/2020). And that the relative capabilities of the cobot was presented as 'much more advanced' than machines, where,

> “if something hits the robot it will stop and put itself out of the way and it will tell you I’m not moving somethings not right here, something has hit me. Where my machine would just keep going… so if I stick my hands in the blanks [moulds] it would just keep closing on my hand, it will not stop” (Dave)

Trust on this level is felt and expressed as maintaining safe distances (between worker-cobot and worker-hot/powerful materials or machinery) or minimizing dangerous physical contacts. The role of tactile and proximity sensors in cobot design is a well-researched area (see section 2) and has potential to contribute to improving these anxieties. However, on another level trusting relationships needed to be formed with respect to accountability for production quality. Barry reflected this as he identified ‘trust’ as one of the main barriers to fully accepting the cobot,

> “we have all of these machines and technologies to check things but at the end of the day it’s down to the human to spot the defects to fix the defects” (06/02/2020)

Swabbing now exemplifies a part of the production process that could be affected by either manual or robotic methods of physically interacting with the moulds but also where it can be difficult to diagnose the source(s) of any defect accurately. Therefore, developing trust in performance and production outputs came into sharper focus in this context. For Barry issues of accountability and trust became more important when “things go wrong” and there is someone or something to blame. This articulation of trust may have implications for informing iterative design processes that are considered in our final remarks but first we assert the main contributions of this paper that are theoretical and methodological in nature.

8 DISCUSSION OF CONTRIBUTIONS

This paper, and the ethnographic narrative it presents, *Touching Distances* has demonstrated that the presence of an industrial cobot in the wild has implications for tactile and affective ecologies even in industrial contexts where there are absences of direct touch, or only very limited/regulated touch opportunities between human and robot. A sample of selected descriptions of research encounters exposed how touch practices and experiences were (subtly but significantly) reorganized within a glass factory through the introduction of new industrial technological methods.

The value of this paper’s theoretical and methodological contributions lies in their suitability for providing rich contextual insights on the complexities of touch and affect. Through the ethnographic narrative our framework and its three constituent analytical planes (material, experiential and social) have been empirically developed to articulate how tactile-affects are: (1) multi-layered; (2) multi-directional; and (3) dispersed across time and space. These developments extend previous qualitative of work that has identified the ‘ripple effects’ of robots entering the workplace [36] by offering a framework to trace such dynamics. Elaborating upon and illustrating these theoretical assertions the narrative acted as a vehicle to convey how tangle passages of tactile-affects might be operationalized in an industrial setting. This decentred the framing of touch as direct interaction or human-robot interface, to shift exclusive attention away from the physicality and embodiment of the robot to attend to wider mediations of the context-of-use. As such, this paper offers an empirically grounded framework that is sensitive to the intimacies between touch, affect and context; contributing an alternative path that responds to the challenges highlighted within dominant theory and method in HRI – such as current approaches to evaluate ‘effective interface design’ and measure ‘affective touch’ (see sections 2 and 4 respectively). The framework builds on growing appetites within HRI to redraw and extend the boundaries of the spaces and scenarios where the ‘social’ and ‘affective’ may be deemed as important [37]. In doing so it generates ways to capture touch and affect that go beyond individual humans and individual robots engaged in a direct interaction [46], and has scope to inform how industrial contexts may develop and integrate cobots being sensitive to workers' experiences. The framework may also have purchase across other strands of HRI research that seek to better understand complex and dynamic implications that *emerge* in-situ.

This paper does not seek to provide concrete design recommendations for the development of swabbing cobots or for how this glass factory should shape the workflow or environment. However, our framework contributes to advancing human-centered research and design processes by offering routes into generating highly contextual accounts of how industrial robots affect the material, sensory and social dynamics of labour by bringing touch into focus. As such, the framework introduced in this paper (see section 6) and illustrated (see section 7) should be read as a resource to guide research rather than a framework *for future collaborative designs*.

Ethnographic methods were employed with a view to generate contextual and textured accounts of touch and affect [38]. Our approach traces passages of affect as they emerge in, and circulate across, the field rather than reductively targeting phenomena to measure and address, by preselection or artificial initiating interactions/scenarios. That is, it is more responsive to context and complexity than current approaches afford. However, the framework and complementary methodological approach we propose has limitations. Most notably, given the primacy of contextual and textured accounts findings are less generalizable than other quantitative (and some qualitative) approaches. In addition, the analytical decision to orientate this sensory ethnography to touch served to elevate the themes of touch (or touching distance) and its technological mediations over other sensorial and social dynamics.

In spite of these limitations, this paper contributes to HRI through its argument for an expanded view of affect and touch. The paper emphasizes the power of understanding affects within an "environmental or ecological context" [43, p.89], where individual touch encounters have a range of historical, social and material traces that need to be accounted for. That is, we have shown that affects do not only travel directly from body to body but also through dispersed "world–body" [2, p.13] relations. This extended analytical framework and methodological approach to trace tactile-affects therefore offers a more integrated perspective on touch in HRI that accounts for social and sensory dynamics, moving beyond purely tactile or physical interaction. Such an approach, we argue, is both timely and needed in a moment where novel and *intimate* collaborations between human and robots being are ushered in to mark industry 5.0 [9].

In summary, this paper has set an alternative research agenda that aims to smooth over methodological gaps within industrial human-robot collaboration research (section 2) that currently relies on ergonomics, cognitive engineering, and robotics to inform design processes [10]. This body of work asserts features paramount to develop cobots for factories of the future, including enabling mobility, manipulation [47], gesture/touch interactions [15], [47], and by keeping humans in the loop during joint task execution and tactile tasks (such as screwing) [16]. These represent useful and generalizable design recommendations for effective human-robot collaborative interfaces, but they are largely restricted to technological architectures. In contrast the approach illustrated in this paper generates holistic and contextual insights that, in turn, may feed into iterative design processes where affects for workers may be identified and addressed - regardless of whether they are directly *caused* by bounded (tactile) interactions with the robot, or not.

Future research building on the socially orientated framework of touch and affect described in this paper has the potential to positively shape workers' experiences and thereby begin to rebalance current design emphasis placed on maximizing productivity through 'effective interfaces' [14]. The framework therefore has a sociopolitical function, motivated to offer fresh analyses that stretch design processes beyond the narrow remit of developing *effective* interfaces for optimizing production towards creating positive *affective* ecologies and conditions of labour. Because the socially orientated framework we promote captures affects as they emerge and circulate in-situ we position its utility in informing iterative design processes through industrial research that shifts focus from effect to affect. In other words, the purpose of this framework is to stimulate and guide research that asks: what happens when specific cobotic designs enter vibrant social and sensory industrial contexts? And what can be done to positively influence the affects this has on the workers? This study considered these questions in a glass factory with newly installed swabbing robots. Whilst the paper's contribution was not to inform design recommendations, the themes it revealed show the potential of the framework for the iterative design processes. These include: interacting with aspects of workplace culture around 'handling the heat' through training and technology; improving reliability and fix-times or developing contingencies so to minimize disruptions to workers when cobot is out of action; developing processes and quality control systems that enhances the acceptability of, and trust in, cobots; understanding workers' overarching predispositions towards robots so that the function and benefit of the technology can be communicated (negotiated) with them, speaking directly to their hopes and anxieties. Such themes open up new and complex considerations around how the material production process is designed in relation to the tactile experiences of workers and the sociosensorial contexts. As such the ethnographic narrative demonstrates how the proposed framework and method could be used to guide research that stimulates new conversations between workers, employers and those designing future robots.

ACKNOWLEDGMENTS

This research is funded as a part of the IN-TOUCH project, a European Research Council Consolidator Award (Award Number: 681489).

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