Future touch in industry: exploring sociotechnical imaginaries of tactile (tele)robots

Abstract

This paper explores sociotechnical imaginaries for industrial robotics. It is motivated by the prospect of promoting human-centred industrial futures. Investigating the tactility of labour through a critical social perspective the research attends to the future of tactile (tele)robots and elaborates on the concepts of pedagogic, collaborative and superhuman touch. These concepts are offered as starting points to foster productive dialogues between social scientists, roboticists, environmentalists, policy makers, industrial leaders and labourers (e.g. union representatives). This paper is framed through literature and ethnographic fieldwork that contextualises and maps the dominant sociotechnical imaginaries for a future touch in industry, identifying the role of a comparative-competitive frame in sustaining a splintering of the imaginary towards utopic and dystopic extremes. Against this, the paper draws on interviews with leading roboticists to chart alternative futures where humans and robots may work together as collaborators, not competitors.

Key words: sociotechnical imaginaries; industrial futures; tactile robotics; telerobotics; touch; manual labour

1. Introduction

This paper contributes to the reimagination of human-centred industrial futures. The research that informs our argument, and grounds our conceptual contributions, was conducted as part of the [**name of project**], an interdisciplinary exploration the social and sensorial dimensions of touch and its technologically mediated futures (see Author et al., 2020a).

The empirical and imaginative focus for this article is concerned with exploring and disrupting dominant sociotechnical imaginaries (Jasanoff, 2015; Mager & Katzenbach, 2021) of a new generation of robots that are entering industrial settings, many of which have enhanced dexterity and are equipped with the ability to touch and be touched in new ways (e.g. gaining tactile information through sensors, providing haptic feedback to human co-workers). In a moment of inflated expectations and anxieties around a 4th Industrial Revolution (Zamalloa, 2017), the paper homes in on two types of future-facing technologies within industrial robotics that have potential to remake touch across sectors: tactile telerobots, and tactile robots.

Tactile telerobots are controlled remotely by human operators who gain a 'sense of touch' from the robot through haptic feedback and other multi-modal methods. These robots are not yet widely domesticated in industrial contexts, however, their new tactile capabilities (e.g., novel possibilities for workers to touch objects at a distance) are imagined as having the potential to radically transform how touch works in industry. Remote manipulation aligns with the rhetoric of technological solutions that seek to distance workforces from dirty and dangerous materials (Fishel et al., 2020).

Tactile robots are gaining an 'active sense of touch' (e.g., Lepora, 2018) or the ability to select and refine sensations in a purposive and exploratory manner. Developing tactile robots with these capabilities is envisioned to have widespread technological applications (Lepora, 2018) and is imagined to be revolutionary as they merge physical, robotic, and human worlds into new and intimate co-operations (Nahavandi, 2019).

The novel and expanding capabilities of both tactile telerobots and tactile robots (herein, we use the term tactile (tele)robots to encompass both) do not afford robots to *feel* in a comparable sense to humans. However, as presented through the narrative of the paper, there are potentials for such technologies to complicate how touch operates and is

experienced across various manual-automated production processes. Aligned with critical perspectives developed in relation to other emerging industrial technologies, we begin by recognising the potential for tactile (tele)robots to: disrupt practices within established work environments (Pekkarinen et al., 2020); and transform the social relations of labour in which they are embedded (Avis, 2018).

The possible implications of such transformations are, however, complex and unknowable – complicated further still through an awareness that the future of technology and labour will remain caught in a web of wider economic, environmental, and political struggles. The sociotechnical imaginaries encountered through our research are not isolated from wider sociopolitical and sustainability issues, however, it is beyond the scope of this paper to equally attend to this vast complexity or to recommend definitive future directions for the field. Instead, our analysis is explicitly motivated by a desire to reimagine "better futures" (Coleman, 2017; Pink, 2021) for industrial (human) workers, and guided by social conceptualisations of touch. Specifically, this paper is primarily concerned with the touch futures for labourers whose production contexts may be directly impacted through the technologies in focus. This intentionally narrow focus has limitations, in that it does not focus on the hidden labour operating behind the scenes of highly autonomous industries or environmental issues. However, this refined focus is valuable in anchoring the discussion to our critical orientations and handling the complexity.

To this end the paper first offers an overview of the sociotechnical imaginaries of industrial robots to trace dominant and contested themes that are stabilised through a *comparative-competitive frame*. The ways in which touch grips and leaves its mark on these imaginaries, through its social and sensorial import in manual labouring is unpacked. The history and future of tactile (tele)robots are located within this framing. The theoretical basis, critical orientations and multi-sited sensory ethnographic methods that underpin the research are explicated. Then the discussion first empirically charts sociotechnical imaginaries of manual labourers and second the future tactile (tele)robots *for* industry. Through this we introduce three concepts (pedagogic, collaborative and superhuman touch) and conclude by calling for productive dialogues between diverse stakeholders and disciplines to inform future development, integration, or rejection of tactile (tele)robots across industry.

2. Literature Review

2.1. Dominant and Contested Sociotechnical Imaginaries of Industrial Robots and Touch

Future imaginaries of robots have been "tied to the promise and threat of the liberation of human laborers" (Atanasoski & Vora, 2020). Stories of automata far predate their invention. Multiple reviews of the social histories and imagined futures of robotics uncover stable but contested themes that resurface from love to war (Royakkers & van Est, 2015), salvation to destruction (Richardson, 2015), and utopic to dystopic narratives (Wajcman, 2017) that reflect tendencies to view robots through a lens of science fiction and lack technical grounding (Szollosy, 2018).

Such contested (and extreme) themes while ever present in the sociotechnical imaginary of industrial robotics are more palpable in the current moment shaped by an overarching narrative that the industrial robotic revolution is arriving (Nam, 2019; Pawar et al., 2016; Zamalloa et al., 2017). The sociotechnical imaginaries that 'swirl' around Industry 4.0 (Avis, 2018) and the discourse of the 'rise of the robots' (Bissell & Del Casino, 2017) are powerful and remain contested in the contemporary industrial context.

Touch grips and leaves its mark on industrial stories, struggles and sociotechnical imaginaries. Classen's (2012) analysis of the changing role of touch during the industrial revolution (i.e. the move of production processes from skilled hands to the standardised metallic touch of machines) exposed shifting 'tactile orders' that resonate more widely with epochal sociopolitical struggles. Workers' daily production practices and experiences of labouring were revolutionised, stoking hopes and anxieties connected to the longstanding sociotechnical imaginaries of automata and labour (Atanasoski & Vora, 2020; Cave et al., 2020; Szollosy, 2018). We have mapped the 'tactile histories' that capture the technological transformations of industries relevant to this research, from tool-use to machinery to the current moment, elsewhere (Author et al., 2021a). While the novel affordances of tactile (tele)robots are not yet fully realised and occupy the imaginary – directing the empirical focus of this article – this historical review raised questions around whether recent (and future-facing) advances in industrial robotics signals a *possible* step change in the relationship between labourers and the modes, tactilities, and technologies of production.

Contemporary social research continues to investigate the ongoing sociopolitical struggles that accompany emerging, and future, sociotechnical and tactile arrangements of labour. For example, the social impacts upon urban geographies in the wake of transforming manufacturing processes have been examined (Grodach & Martin, 2020). Findings indicate that 'low-tech, high-touch' manufacturing processes are being spatially restructured and concentrated in the context of 'post-industrial' cities and Industry 4.0. The changing role of touch in industry, and its redistributions, continue to reverberate beyond the factory rippling across the socioeconomic and material organisation of the city. More so it is often imagined that robotics will have an inevitable and wider reaching effect on workers' sociosensorial and economic futures (Nam, 2019). Nam's study on robotic automation reveals the dominance of a techno-determinism that is usually accompanied by a splintering of optimism (utopic) and pessimism (dystopic) sociotechnical views.

We posit that the splintering of the imaginary is underpinned by a perception/fear of "robots as competitors to humans" (Richardson, 2015, p.63). Anxieties of the devaluation of human touch and labour registers and manifests differently across sections of society, such as through class and education (Avis, 2018) and have become entangled with racialized and gendered cultural imaginaries through dominant narratives (Atanasoski & Vora, 2020). In response to, and anticipation of, continued technological developments transforming industries we problematise a comparative-competitive frame (empirically illustrated in 5.1) as functioning to stabilise dominant and contested sociotechnical imaginaries of industrial robots.

Tactile (tele)robots inhabit this broader contested history and future imaginaries. There are potentials for these relatively new and rapidly developing robots to disrupt established industrial practices and social relations. Since the advent of industrial robots that are able to sense their environment (see Husband, 1982) advancements in tactile (tele)robotics have sought to restructure industrial processes to achieve an 'unmanned facotry' that strips (or displaces) manual touch. There has been no shortage of hype surrounding recent advancements in haptic technologies (Parisi et al., 2017) and such promissory claims around the potential for haptic technologies connect tactile (tele)robots to the discourse of being at the cusp of yet another industrial revolution (Pawar et al., 2016; Zamalloa et al., 2017). In framing this paper, we view such 'revolutionary' trajectories as stoking hopes and anxieties based on human versus robot competition. With an explicit theoretical and critical orientation, outlined below, this paper seeks to disrupt this dominant framing through the amplification of pedagogic and collaborative touch futures.

3. Theoretical and critical orientations

We attend to the social and sensorial dimensions of touch through an interdisciplinary framework that brings together insights from multimodality, sensory studies, and design (Author et al., 2020a). Our approach connects with a growing body scholarship that produces nuanced accounts of the social, cultural, and political dimensions of touch (Parisi et al., 2017) – and the sociotechnical imaginary of touch (Author et al., 2021a). The social sciences have contributed, through theoretical-driven and empirical-grounded research, to our understanding of both how and why touch matters. In material culture studies, for example, (Pink et al., 2014) attends to the hand and the materialties it comes into contact with as an analytical entry point to understand health and safety in care work. Likewise, in (Author et al., 2021b) we 'filtered touch' to trace how new robotic technologies impacted upon the social and sensory dynamics of manual labour in dirty and dangerous industrial settings. In this paper, we extend our gaze to the future of touch in industry, to engage with (and shape) how they are imagined/pursued. Through this our critical orientations are geared towards promoting human-centred approaches such as those developed in design anthropology (Pink et al., 2021).

Specifically, we operationalise a social conceptualisation of touch to explore and challenge dominant sociotechnical imaginaries (Author et al., 2021a) that circulate in the field of industrial robotics. Being collectively held and institutionally stabilised (Jasanoff, 2015) sociotechnical imaginaries tend to reflect dominant social and political orientations to technologies. They are bound to, and reproduced through, organisational discourses, production practices and social relations. The dominant ideology of techno-liberalism stimulates imaginations of futures where human labourers are *freed* from dull, dangerous and degrading (e.g. dirty) work (Atanasoski & Vora, 2020) – themes that remain prevalent in the tactile (tele)robotics literature (Fishel et al., 2020), contemporary empirical investigations (Author et al., 2021b) and media representations (Robotics Online, 2019).

In this paper we adopt a critical position in relation to this backdrop by reflecting conceptually upon how we might escape from the limits of dominant sociotechnical imaginaries (Markham, 2020). Our critical approach is inspired by Mager & Katzenbach's (2021) conceptual elaborations of sociotechnical imaginaries as *multiple* (i.e. multifaceted, dynamic and expansive) rather than monolithic, linear and limited visions of the future. Consequently, our analysis and discussion are primarily concerned with muting concrete exemplar scenarios in favour of generating concepts of human-robot organisations through which a range of alternative futures can be imagined, problematised and pursued. These contributions are products of our motivation to explore the *textures in-between* utopic and dystopic extremes, that was spurred through Cave et al.,'s (2020) argument for the need to privilege sophisticated and complex narratives of alternative technological futures to inform future thinking around social, ethical and political issues.

4. Overview and Design

This paper presents findings from a multi-sited sensory ethnography based in two industrial settings in the UK. During the ethnography themes emerged around the hopes and anxieties for the future of touch in industry. Tracing emergent themes is central to the reflexive approach of multi-sited ethnography (Falzon, 2016). We operationalised the concept of sociotechnical imaginaries (outlined in previous sections) to descriptively map and probe the future of touch in industry in a context where tactile (tele)robots are largely "undomesticated, unstable and in labs, rather than 'in the wild'" (Author et al., 2021b, p.14). Retrospectively,

two broad phases reflect the research process and organise our discussion: their methods and focus are outlined below.

4.1. Phase 1: sociotechnical imaginaries *within* industrial settings

In phase 1, the field researcher was situated *within* two industrial settings (a Glass Factory and Recycling Centre) where new robotic technologies had recently entered. A total of two weeks fieldwork was conducted within these industrial settings. The method of 'tactile apprenticeship' guided the ethnographer to participate in touch practices and interactions wherever possible (such as picking on the waste line and inspecting bottles for defects). Sensory interviews were conducted with manual labourers and office staff to stimulate reflections on the role of touch and discussions on their imagined futures. Eight of these interviews (lasting between 30 minutes and 1.5 hours) were recorded and transcribed and fieldnotes captured additional exchanges with participants on these topics throughout the site visits.

In interviews and informal exchanges with workers diverging visions of the future were commonly discussed and were productive in shaping the socialites of the present (as elaborated upon in 5.1). Workers would often discuss the future of their working lives set within the context of roboticization and in response to planned move towards 'Industry 4.0 ready lines' in both industrial contexts. In these conversations future industrial practices and working relations with robots were imagined and anticipated, eliciting both hopes and anxieties. Responding to this emerging theme fieldnotes captured organisational discourse and workers conversations, tracing the dominance of a comparative-competitive frame, and a splintering of the imaginary that is produced by it. Such findings acted as a counterpoint to the analysis of phase 2.

In parallel we were conducting fieldwork at a robotics company that make advanced tactile telerobots (3 days) and attended robot networking and training events in the UK (and online). Themes generated from this 'future-facing' site (see Author et al., 2020b), interacted with the importance of the sociotechnical imaginary *within* industrial settings, stimulating a reorientation through which phase 2 emerged.

There is limited space to unpack these methods here, but we have detailed them elsewhere (Author et al., 2020b, Author et al., 2021a, Author, forthcoming 2022).

4.2. Phase 2: sociotechnical imaginaries a future touch *for* industry

In phase 2 we traced the significance of sociotechnical imaginaries and engaged further with roboticists who, through their work, envision a future touch *for* Industry. Four interview participants were selected on the basis that they are the leading figures in their respective fields (both academic and industrial) and are currently involved in developing tactile (tele)robots for the future (introduced later). Two of these participants were based in the UK and two in the US.

In-depth sensory interviews were guided by topics generated from the analysis of phase 1 and were tailored to the participants expertise and interests. Participants were prompted to talk about (and physically demonstrate) the possibilities for tactile (tele)robotics and how it may impact on the tactile nature of work in the future (for more details see Author, forthcoming 2022). The interview design supported these participants to imagine how possible technological advances of tactile (tele)robots may have implications for workers, and wider society. These conversations were inherently speculative. 'Likely' futures were discussed and yet the emphasis on speculation meant that the possibilities explored together

were understood as not inevitable, but feasible based on the technological scope for tactile (tele)robotics in both existing and yet-to-be-conceived industrial settings/societies.

Interviews were conducted online and lasted one hour. Transcripts were first coded for common and contrasting imaginaries for robotic touch and sub-categories were developed. Additional themes produced through this coding process were refined through their relevance to touch and then cross-referenced with: (1) data generated through participant observation of robot makers from phase 1; and (2) the wider robotics literature - to locate participants imaginaries within technical, political, ethical and social debates that are well-established throughout the history of robotics.

All interviewees provided informed consent and were given the opportunity to read the article, to comment and ensure accurate reporting of the interview data. P1 is Professor of Robotics and AI and the principal investigator of a large project conducting fundamental research into the advancement of tactile robotics. P2-4 are from different organisations that together form a research partnership that has created a state-of-the-art tactile telerobot. P2 has particular expertise in tactile sensors, P3 in dexterous robotic hands, and P4 in haptics.

4.3. Researchers' positionality and the balance of voices for the future

We engaged with manual laborers, industrial stakeholders, and roboticists to gain a sense of their (differing) perspectives and imaginations. Throughout the ethnography we were not positioned as neutral observers. Our motivation to help forge "better futures" through social research (Coleman, 2017; Pink, 2021) informed our human-centred approach shaping our engagement with participants as well as our analytical process. Viewing the splintering of utopic/dystopic futures as limiting the space for alternative imaginaries to emerge our analysis sought to generate concepts that might help to challenge dominant frames and foster productive dialogue. These motivations reflected and informed the balance of voices presented in this article.

To develop and emphasise human-centred futures, our starting point is the voices of the manual workers - their hopes, anxieties and expectations. These voices contextualise the need to amplify pedagogic and collaborative touch, that hold value to reimagine and pursue desirable industrial futures. The imaginaries of leading experts in the field of tactile (tele)robotics, however, have more agency in creating future technologies that will shape future industries, thus making them significant. Further, by affording the sociotechnical imaginaries of experts more space in this paper we attempt to distance our contributions from the lens of science fiction (Szollosy, 2018) taking seriously the technical realities that inform design and constrain development, or to remember "that the real is always asserting itself in the making of robots" (Richardson, 2015).

5. Findings and Discussion

5.1 Future touch *within* industrial settings

This section evidences the significance of day-to-day (tactile) practices and the social relations within the industrial sites in forming and reinforcing dominant sociotechnical imaginaries. Such tactile and social dynamics were understood as being framed through worker-robot comparison and competition. This framing, we argue, is a central contributor to the sustainment of the dominant and contested sociotechnical imaginaries of industrial robotics and the future of touch. The section concludes with one atypical instance where two workers imagined future industrial settings that evoke alternative industrial practices and relations that could challenge the dominant framing. This example acts as an opening for

industrial futures where workers no longer guard against robots as competitors but as technologies that they work with in new ways.

5.1.1 Organisational sociotechnical imaginaries

Starting with organisational discourses, the following fieldnote excerpt reflects how visions of the future work were carefully crafted in the Glass Factory,

> 'Crafted Futures': Stepping into the reception at the Glass Factory I am immediately struck by a projection of an industrial and societal futures. A large banner, proudly positioned, colourfully presents the message "Great People – Great Place to Work – Great Future". A corporate video playing on loop contributes to this message, bringing together the 'bright futures' of the company, employees, the environment and society through the promise of Industry 4.0 and the technological developments in glass manufacturing that are presented as inevitable.

In this public facing space, but also in the message boards and conversations in the 'backstage' of the factory, a projection of the future has been crafted by the organisation. The narrative promotes the benefits of technology for workers and customers alike, and this story seeps from the materials (e.g. banners, posters, videos) to the imaginaries of informants as they discuss the future implications of technology to the sociosensorial conditions of their labour. The telling of these 'positive' narratives of the future was emphasised in both field sites and frequently articulated through managerial voices and were also rearticulated by many manual labourers.

Throughout fieldwork (particularly in introductory meetings/conversations) participants/gatekeepers at a managerial level would pre-empt and provide a counter narrative to threats of job losses and other 'negative' connotations associated with advanced automation. The unified front of the messaging suggests, to some degree, that these narratives are rehearsed preformed/crafted responses. As such these narratives represent powerful sociotechnical imaginaries because they are stabilised through performance (Konrad & Böhle, 2019). One example of this was when a manager in the Glass Factory discussed how journalists have visited before, being interested in their new robots, but 'misreported' the future implications for the factory and workers. At the end of the ethnographers' stay the manager returned to this prior experience and reflected, "the general opinion is, 'there are robots, someone is losing their job'. They don't understand the process. You've watched it for days now, you can see that these guys still have a job to do". Other responses drawn from both sites included: citing increases in company employment rates as new technologies have been integrated; 'upskilling' of job profiles; and improving working conditions by moving labourers away from dirty and potentially dangerous materials. Such efforts to craft and present a particular vision of the future (in the displays, texts, videos, and practised responses) demonstrates an acute awareness of counter cultural and political narratives that infuse the contested sociotechnical imaginaries of industrial robotics from outside of the institution – and that can permeate in. These organisational narratives reflect the dominant sociotechnical imaginaries that the field researcher encountered within industrial settings – they illustrate the utopic vision of future sociotechnical industrial configurations where workers are retrained and have better working conditions. For the argument of this paper, it is not important to predict whether such imaginaries are possible or likely, rather our analysis demonstrates that the same projected technological developments can also stoke workers' anxieties around future working practices and relations – with a resultant tendency to splinter the imaginary towards articulations of utopic and dystopic futures.

5.1.2 Workers' sociotechnical imaginaries

Manual labourers engage with and repeat many of these institutional stories. Yet at the same time the perspective that workers bring to (re)telling of these narratives, including departures from organisational discourse, highlights varying degrees of anxieties (and hopes). These differing perspectives reflects a continuation of the contested (and polarised) sociotechnical imaginaries propagated through dominant techno-liberalism (Atanasoski & Vora, 2020) and for a proportion of workers stands in contrast optimistic technological imaginaries (Nam, 2019) promoted through the organisation. Indeed, our findings show that workers sociotechnical imaginaries were not homogenous, and were formed through a wide range of sources, including: engaging with organisational discourses of the future; exposure to cultural/political narratives outside the workplace; and are grounded in their day-to-day (tactile) experiences of working with the range of manual-automated processes that characterise their labour. In support of this final point, the fieldnote below exposes the significance of a *comparative-competitive frame* against which future work is imagined and through which the anticipated value of their manual touch is considered,

> Grounded futures: Glass manufacturing is frequently been described by labourers as "a dark art", "like cooking" and an "art form". Even in this highly mechanised and automated context, workers often draw attention to these analogies and point to the *grey areas* of the production process. Against this they will highlight their unique abilities to gain a *feel* for the machines, materials, and process that sets them apart from mechanical processes and robotic technologies – now and into the future. One laborers' statement when envisaging their future workplace typifies this "there is little things in the job, where as a human, you're like that works… not everything has to be identical so we will run with it. [Concluding that] it [the robot] is only doing what it set up to do. But you need the human eye [and feel]. So, I don't worry about technology taking over".

Observing differences of the productive value of their manual and tactile competencies against those of the new batch of cobots forms a basis from which their sociotechnical imaginaries emerge. Their ability to sense and *feel* their way through any grey areas of production align with (Welfare et al., 2019) findings that suggest that workers tend to assert that robots are unable to compete (in the short term at least) because they are viewed to "lack of human expertise or touch; robots cannot see mistakes and make adjustments the way a human can, and with a high variation product" (p.81). In the Glass Factory and Recycling Centre, these imaginaries also aligned with organisational narratives around upskilling job profiles and moving workers into more cognitive roles away from touching dirty and dangerous materials. For the most part these futures were accepted, welcomed and desired, with some social notable caveats that are also sustained by the comparative-competitive frame. These hinge on the possibilities for changing industrial practices and relations in ways that the individual anticipates as detrimental.

In the Recycling Centre one member of staff considered that pickers might resist a rapid rate of technological change, "will the pickers get anxious over the speed of change? […] we might end up with a situation like when those people destroyed machines in the industrial revolution" (Office Staff). This staff member is imagining and cautious warning of the possibility of neo-luddism if the *practice* of manually picking waste off the line became redundant too quickly. The possibility for such responses is well established elsewhere in the literature (Kryszczuk, 2017). These future imaginaries intersected with cultural imaginations of gender and ethnicity (Atanasoski & Vora, 2020), with conversations around who will be touching dirt in the future. Furthermore, specific issues that related to workers trusting robots in terms of performance were also imagined as becoming more central to future contexts

where, “at the end of the day I am the one who is made responsible [for outputs and meeting targets], not the robot” (Glass Factory worker). Examples like these expose the ways in which workers, through imagining changing industrial practices and relations, come to anticipate future technological developments with a critical imagination of the what the social and sensorial implications for them might be. Whilst this complex process may be highly individualised workers engage with the prevalence of the comparative-competitive frame, through which a splintering of the sociotechnical imaginary is sustained.

These ethnographic insights depict the overwhelming dominance the familiar and splintered sociotechnical imaginaries akin to those reviewed in the framing of this paper. One exchange with two labourers in the Glass Factor that have experience of working alongside collaborative robots, however, revealed possibilities of alternative sociotechnical imaginaries. The two labourers speculated that in the future technology will “*just* become more incorporated” within the process and that a part of their role will be to “coach them [industrial robots] and better them”. These imaginaries hint towards future robots that are not necessarily positioned as competitors. We explore and expand upon these possibilities through the technological imaginaries of roboticists in 5.3.

5.2. Future Touch *for* Industry – dominant and contested sociotechnical imaginaries

Before exploring this opening further, by expanding on the notion of collaborative and pedagogic touch, in this section, we identify and discuss some of the dominant and contested sociotechnical imaginaries that are established within robotics research and development. In the first subsection we unpack the dominant visions in industrial robotics through presenting some of the ‘revolutionary’ sociotechnical imaginaries *for* tactile (tele)robots. Then contested imaginaries are expressed through three key topics that were frequently raised and act as a counterweight to industry hype. Together this section provides a needed backdrop of the relevant dominant and contested themes that cannot be detached from the sociotechnical imaginaries that are elaborated upon through the exploration of the textures in-between that follows.

5.2.1 Revolutionary sociotechnical imaginaries of a future touch in industry

There were relatively stable projections that reflected a degree of inevitability of technological progress where robots will play an increased role in industry and society – although the details and extent was projected as both uncertain and contested. Even though the development of more sophisticated tactile (tele)robots was, for the most part, considered overwhelmingly likely in the ‘foreseeable’ future a number of technological and economical hurdles were identified. The future development and uptake of tactile (tele)robots within industry was also understood as dependent on how it competes (in terms of economic viability and market demand) against tangential technologies (e.g. exoskeletons and Brain-Computer Interfaces). Therefore, in a similar fashion to manual laborers, these roboticists situated their current and future creations within a competitive industrial context where the productive value of touch is paramount. For example, P2 reflected that,

> “*I think telerobots are going to make it apparent how important tactile sensors are - or prove that they're not valuable. The reality is, these telerobotic systems add a lot of costs by introducing the touch element. And if those can’t be substantiated by improved value, then maybe tactile sensing won't be useful enough to meet industrial applications, or certainly not at low cost*”.

As such, future developments within the field were overwhelmingly viewed as dependent on wider economic forces, reflecting a ‘productivity-centred’ ideology that constricts the

imaginary through anticipated market value and forces. In contrast, environmental issues were seldom raised in these interviews as a key factor in shaping the future development and implementation of tactile (tele)robots. One exception consisted of P4 describing the future of tactile (tele)robotics as contributing to sustainable futures because "you don't have to travel as much as it's environmentally greener". Such a statement reflects industry tendencies for technological optimism (Miller, 2020), highlighting the need for critical imaginaries and voices to be elevated.

Acutely aware that larger economic systems are the dominant force shaping the role of tactile (tele)robots in future industry, interviewees also projected beyond these uncertainties to offer promissory imaginaries of tactile (tele)robots. These represent long-term and abstracted futures that connected with how they reflect on their current work and its trajectories. P1 captured the revolutionary imaginary in relation to tactile robotics stating that "given that many people on the planet are employed for their hands, if it is possible to do many of those jobs more cheaply with a robot, you could see that would have a massive *disruptive impact*". Whereas P4 reflected that, if realised, a "one-to-one relationship between what you're doing and what the [tele]robot is doing would really allow you to *teleport*". With interviewees often gravitating towards such abstracted long-term possibilities (as expanded further in 5.3 in relation to collaborative and pedagogic touch) the wider social and sensory implications of any anticipated changes to industry were stipulated as not necessarily negative, but rather as "hard to predict" (P1).

5.2.2 Contested sociotechnical imaginaries for future touch in industry

Here we briefly unpack three sub-categories that are contained within the overarching theme of contested imaginaries for robotic touch: "the jury is out on touch"; "the art of the possible"; and issues of controlling touch. These non-exhaustive themes of contestation reflect some of the complexities of touch that infuse the sociotechnical imaginaries of industrial robotics. These three themes of contests, that exist within the robotics community, expose more cautious projections than found in discourses framed through industry-hype (see 2.1) and challenge simplistic assumptions that the revolutionary and promissory industrial projections are being pursued in uniformly agreeable ways. Furthermore, distilling these themes in relation to technical realities and philosophical debates that characterise the history and current moment of field identifies important topics that remain relevant to the concepts of pedagogic and collaborative touch elaborated upon in the next section.

The 'jury is out on touch' was a commonly used phrase identified during fieldwork in phase 1. Within the community engineers and company strategists there were some that are converted to the importance of touch (i.e. haptic feedback, tactile sensors, and dexterous manipulation of objects) within robotics. To support their position some individuals pointed towards empirical studies that gave weight to their reasonable working hypotheses and would also reinforce their position though what they recognised as 'anecdotal examples' that imply the importance of touch. Others were unconvinced and cited competing empirical findings and anecdotes. Most, however, were largely agnostic and argued that making judgments about the importance of touch is contingent on the specific application. A key basis for judging the importance of developing more sophisticated tactile (tele)robotic systems for future industries was whether, or not, the 'value' it adds to production can be clearly articulated. In relation to the development of advanced tactile telerobots P3 offered a baseline 'litmus test' through which judgements of value can be speculated upon. This test consists of considering whether a tool on the end of a long stick could perform the task to a similar effect of a sophisticated robotic system, as this is most likely a much cheaper solution. The framing of 'value' through a productivity-to-cost ratio rather than in terms of their affordances/architectures, by roboticists, overlooks some of possible the technological

distinctions between tools and complex robotic-human systems. Whereas from the perspective of labourers working with cobots, such advanced technologies differ from familiar tools in terms of how they interact with them and therefore their status as tool, machine or collaborator becomes ambiguous (see Author et al., 2021a). Based on productivity-cost value judgements considerations of what type of, and to what extent, touch should be developed in robotics was contested across individual components such as the design of haptic feedback. P4, for example, asked,

> *"How much is too much haptics? How much is too little haptics? There are very strong views towards one way or the other. There are some very vague views one way of the other"*

The second theme that exposes distinct differing view relate to "the art of the possible" versus "narrow engineering solutions" (P3). These phrases capture the ongoing distances between the day-to-day technical challenges of developing robots that feel and the revolutionary speculations of their possibilities. There is a perceived discord here that can be viewed as a productive tension or a useful gap that is necessary for research and development. P3, for example, has deliberately never operated the tactile telerobot to avoid getting consumed by how it feels and entrenched in the current technical challenges in getting touch to 'work' better in the system. Both narrow engineering solutions and unbounded speculative imaginaries are needed to inform and advance the other (P3).

The third well-established and unsettled debate within the robotics community that our interviewees commonly raised concerned the control of a system. A contested technical imaginary of control existed on a practical plane when judging effective control systems for specific applications (e.g., where should control of touch be distributed and organised in order to perform defined tasks effectively). More fundamentally, the issue divided social and ethical imaginaries across a 'philosophical' plane. Speaking about relative degrees of Artificial Intelligence (AI) and human autonomy in telerobotics P4 stated,

> *"I'm a little bit on the fence here. I know a lot of people that would prefer to have AI do all those corrections… [But] if AI takes over too often you might end up fighting it."*

P4 expanded upon this with respect to medical robots and surgery where the consequences of shared control over touch could add 'value' (e.g. "if you are holding the scalpel and accidently drop it, it's good for AI to be able to catch it before it goes into the person") and be a detriment to the system (e.g. "if you drift the scalpel away from something but then the AI takes over and forces it back into the spot you don't want it"). Consequences of the value and disadvantages of hybrid/shared control of touch applies to future industrial use case scenarios and the general reorganisation of production processes. The functional, ethical and social implications of shared control over touch are therefore deeply embedded in the historical and ongoing navigation of the future of tactile (tele)robots (Luo et al., 2019; Sheridan, 1989) and transfer across to imagined human robot collaborations.

5.3. Exploring the Textures In-Between

In this section we elaborate upon the future technological possibilities of tactile (tele)robots as imagined by interviewees with a view to amplify directions that can disrupt the dominance of a comparative-competitive frame (5.1). The concepts of pedagogic and collaborative touch are vehicles for this offering alternative visions for the future of touch in industry. Both concepts are not detached from the points of philosophical (ethical and social) and technical contestation well established in the field (5.2). The provocation of robots developing (or already having) superhuman touch capabilities concludes the section strengthening our claim

that it is vitally important to imagine and take seriously the social and sensorial implications for future workers from a human-centred perspective. The three imaginaries (pedagogic, collaborative and superhuman touch) are distinct but speak to each other and were developed through a common analysis (see 4.4).

5.3.1 Pedagogic touch

> Composite of future imaginaries (pedagogic touch): Imagine future production processes involving highly dexterous, delicate and differentiated tactile competencies to be learned and performed. These types of touch are currently technologically challenging for autonomous robots and might also be dangerous or undesirable to humans. Navigating these production processes would benefit from new ways for humans and robots to learn how to touch together.

We introduce *pedagogic touch* as a concept that generates alternative sociotechnical imaginaries building upon a two-way relationship where humans and robots learn to touch, and through touch, together. Pedagogical touch can become established though an expansive range of possible tactile practices and interactions where sensors, operators, robotic systems and haptic feedback devices learn though and with each other. Being a joint enterprise, this concept therefore has scope to punctuate a comparative-competitive frame. A range of tactile-pedagogical relationships and possibilities are newly afforded (or greatly expanded) through developments in tactile (tele)robotics.

One clear articulation of pedagogic touch is an example of how humans could teach robots how to perform difficult or delicate touches, as explained by P4,

> "*with a really good haptic system you can pick up 50 eggs over and over again, and different variations of how you pick it up […] Never once have you broken egg. And within those 50 cases you've now shown a robot exactly how much force to apply, how to apply it, where to apply it, and all that kind of detail*".

This example illustrates how new tactile practices can be established and incorporated into industrial processes that rely on workers' *coaching* robots to touch through touch – as imagined future relation suggested by one worker in the Glass Factory. The productive value of workers, through this pedagogical relationship, is based on their ability to transfer their tactile competencies (that they have developed through years of manual labour) for particular touch tasks to a robotic system. The possibility for humans to coach robots to touch through touch represents a new (potentially long-term and iterative) working relationship between human(s) and robot(s).

In the other direction, there is scope for robots to coach humans how to touch through several methods. For example, tactile telerobotic systems could be configured to teach humans how to touch effectively and/or differently, in safer conditions. Two differing imaginaries were elaborated upon by the interviewees. The first is built on a dominant design intention in tactile telerobotics of developing a one-to-one (tactile) experience, as discussed previously (P4). Here the objective is to create tactile telerobotic systems that provide 'intuitive' touch experiences for the human operator (P2, P3, P4). The term intuition was commonly used by telerobotics interviewees to refer to the usability of the interface with a robotic system, without the human operator having to undertake extensive training, rather than referring to an intuitive capability of the technology. In relation to this, P3 imagined scenarios where workers safely practice touch tasks without being exposed to dangerous materials or environments.

The second imaginary is where touch feedback (including visual, audial, tactile and force) is intentionally manipulated for a pedagogical purpose. Leveraging technical

possibilities to distort multi-modal inputs and outputs through the use of robotic systems holds great (and largely untapped) pedagogical potential. A scenario that P4 imagines provides one example where robotic systems can help coach human operators through the manipulation of sensory data and feedback, "if you touch something you're not supposed to touch, you can get feedback, so it's like 'Oh yeah, don't touch that'. You can start to enhance the activity and different types of feedback that you can provide". Not only can conceivable training configurations redistribute and manipulate the sensorium with a pedagogic function time may be paused, sped up or slowed down to the same effect (P3, P4).

Together outlining these pedagogical arrangements reveals the expansive range of possibilities to establish new touch practices in industrial contexts for training both human and robotic workforces. Here we emphasise that whilst the teaching and learning of touch may have a dominant direction (i.e., from the transmission of tactile competencies from the robot to the human, or vice versa) there are possibilities for joint learning to occur, at the same time. These technological opportunities can be pursued through human-centred approaches that disrupt the comparative-competitive frame.

We flag here a cautionary note that these multiple possibilities for pedagogic touch may also be exploited through their development and *integration* (Welfare et al., 2019). P4, for example, understood that "if you're teaching a robot through haptics with robotics, you're eventually augmenting and or replacing the human in their task". As such we recognise that the technological affordances of future tactile (tele)robots might not lead to a break from the dominant comparative-competitive frame – especially if driven through narrow economic forces (that were identified as dominant in 5.2). These issues are problematized and explored further through the provocation of Superhuman Touch (5.3.3).

5.3.2 Collaborative touch

> Composite of future imaginaries (collaborative touch): Imagine future sites of industry that have transitioned from Fordist lines to flexible and responsive production processes that is indicated in Industry 4.0, and beyond. These environments may require workers and robots to work together on varied tasks. These types of collaboration are currently technologically challenging with most industrial robots caged and kept separate from workers for safety reasons. Consider then a future where humans and robots harmoniously and seamlessly touch together to perform any industrial task they are assigned or choose.

Collaborative touch is connected to, but also distinct from, sociotechnical imaginaries of a future pedagogical and tactile relation between human and robot. Specifically, collaborative touch refers to the act of touching together in the performance of a task or as part of an industrial process. Tactile collaboration might take two main forms: touching with and through robots.

The first is based on the notion of collaborative robots (cobots) and realising a 'responsive collaboration' between human and robot workers (International Federation of Robotics, 2019). Tactile robotics may come to possess the ability to work *with* labourers in various capacities, locations and on a broad range of tasks. According to P1, one key advantage of tactile robotics is that it could aid collaboration in real-time and in close quarters between workers and robots through improving collision detection, "we have skin everywhere [that is important for] knowing when we hit things […] that's [recreating tactile sensing for robots] obviously very important for cobots". Indeed, collision detection and avoidance is a key area of research in human-robot collaboration (Cherubini & Navarro-Alarcon, 2021) and is a base factor in cultivating user trust in the robot (Maurtua et al., 2017). Developing this trust is central to an initial phase for developing positive working *relations* with cobots (Author et al., 2020b). While there are a number of methods that seek to

minimise collision, tactile sensing capabilities that mimic skin was articulated to have an important role in future collaborative robotics (P1, P2).

Beyond collision detection tactile robotics were imagined to be important to realising the responsiveness needed to perform a variety of tasks as robots come to collaborate with individual workers that have unique dispositions and preferences. Notwithstanding the technical hurdles that "could be difficult to surpass" (Welfare et al., 2019) a closer collaborative relationships between worker and robots where workers continue to use their hands has been noted as desirable within manufacturing (*ibid*). Not only are these important considerations to 'reimagining' the future of work and how worker experiences and conditions can be improved (*ibid*) future robots that embody 'an active sense of touch', closing the loop between sensation and action, can be pursued as a route to overcome and handle the complexities of collaborative touch.

The second form collaborative touch can take is *through* a robotic system. This form of touch collaborations was imagined in multiple and differing ways by the interviewees. For example: a human operating one robot that is teaching or operating another (P4); a non-human operator (e.g., animal-mechanical-natural phenomena) controls the robot (P3); or multiple operators moving one remote robot that is autonomously performing certain tasks (P3). In designing collaborative touch through a teleoperated system the theme of shared/hybrid control (and partial AI) resurfaced as a key discussion point,

> *I don't think it's a black and white thing. You can have partial AI. I mean teleoperation is basically about, partial autonomy. You still need some autonomy of the thing that's being controlled. It's about reducing the complexity of the control for the human user by putting some of that autonomy into the control device, while still giving the human user a sense of agency and sense of control over it* (P1)

Similar to pedagogic touch the ability to distort and remix sensory inputs and outputs is imagined to be leveraged in these future collaborations. For example, when feeding data back to a human (through various sensory modalities) two interviewees (P3, P4) expanded on the possibilities around managing 'cognitive load' more effectively – and that this will have industrial application because the operator will be free to "fight the war, not the weapon" (P3). Both collaborating with and through robotic systems open up expansive imagined possibilities for the future of touch in industry, that include the establishment of new practices and the formation of new human-robot working relations. These multiple possibilities colour the textures in-between utopic and dystopic industrial futures being framed through collaboration, not competition where human labour is directly threatened. We now turn to the concept and imaginary of a superhuman touch that may be harnessed in pedagogical-collaborative arrangements but might also undermine such joint enterprises.

5.3.3 Superhuman touch

From our social and critical orientations, it is vital to imagine and take seriously, the social and sensorial implications of future industrial robots for workers, from a human-centred perspective. We use the concept of "superhuman" (a term used in the robotics company and by two interviewees) touch as a provocation inherent within the technical possibilities afforded by future *tactile (tele)robots*. This provocation strengthens the case that the design and integration of these future technologies needs to be critically explored beyond their productive value. This argument underpins our contribution to join calls for human-centred industrial futures (Nahavandi, 2019; Welfare et al., 2019) to jointly explore and amplify the possibilities for collaborative and pedagogic touch in ways that avoid detrimental social and sensorial transformations within industries from workers perspectives.

The notion of a superhuman touch was articulated by all interviewees through the potentials for tactile (tele)robots to deliver touch to industry at *scale*, and with *precision, reaction, sterility* and the capacity to *store* touch. Whilst these five technical possibilities may be harnessed through the concepts of pedagogical and collaborative touch outlined above, each of them might be drawn upon to imagine futures where robots outstrip and make human touch redundant altogether. As such they provoke, they represent a set of technical possibilities that can be powerful in sustaining the comparative-competitive frame but also in disrupting it.

Scaling touch *refers to the productive capabilities of robotic systems to manipulate, handle and interact with* different scales of materiality. The examples given reflected three axis of scale included size/weight (both microscopic and large) (P4), volume/number (P3, P4), speed (P1).

Precise touch refers to the potential for robots to move and touch in very dexterous and controlled ways whilst also observing tactile data more accurately than humans. P1 explains this, "it [an advanced tactile robot] reconstructs the surface geometry precisely, so it's not like human touch. We don't do that. It takes, if you like, a tactile image of a surface, and it's very accurate, micron level".

Sterile touch was discussed as "a dialect of contamination" (P3). Touch can be contaminating for the human toucher and for the materials they are working with. For example, human touch is expressed as unsterile with P4 describing it as a 'flaw' of human contact where "the dirtiest part of a clean room oftentimes is the person". Furthermore, P3 adds that robots follow (hygiene) procedures more predictably and do not need to leave clean space.

Reactive touch related to latency a defined term in the lexicon of roboticists. P1 speaking of "the limitations of human dexterity [recognised that] we have a very slow latency. We have something like 100 millisecond latency […] There are robots that work at milliseconds". Tactile (tele)robots might seek to leverage this 'superhuman' capacity through the implementation of a robotic reflex system that might react to slip for example and catch objects (P2, P3, P4).

Storing touch is newly afforded by digital technologies and tailored to industry through the development of tactile (tele)robots. This technical potential, according to P4, can profoundly disrupt skills industry whereby complex manual and tactile tasks could be recorded and stored. Capturing and preserving complex manual skills encroaches the relative productive value of labourers into the future.

These sub-categories can generate imaginaries where the productive value of robotic touch exceeds those of manual laborers, and that will make them desirable to competitive industrial sectors. Whilst the same sub-categories were used to inform and develop pedagogic and collaborative touch imaginaries, they can also potentially usurp them. *Superhuman touch* is therefore a provocation that highlights the importance for such technological possibilities to be harnessed towards human-centred industrial futures.

6. Conclusion

The contribution of this paper is the amplification sociotechnical imaginaries that rupture the dominance of the competitive-competitive frame. Through two-phases this ethnography provides nuanced accounts of sociotechnical imaginaries from both *within* and *for* industry that expose dominant ways of thinking about the future and reveals contested themes (Mager & Katzenbach, 2021) on social, technical and environmental planes, and their intersections. We seek to navigate points of contest (rather than to resolve them) in ways that centre human experiences of labour and touch and stretch our collective imaginaries beyond current limits

that are bound to dominant ideologies (Markham, 2020) that we traced through the splintered imaginaries that surrounds Industry 4.0 (Avis, 2018; Bissell & Del Casino, 2017) and the discourse of continued 'robotic automation' (Nam, 2019b).

Based on the imaginaries mapped and critically discussed in this paper we make the case for future research and development to be guided by how such technologies may affect the social dynamics and sensorial conditions of labour, for workers. There are balances to strike between the economic, environmental, and social value of remaking touch across industry – but currently the former is the driving force 5.2. Left unchecked this productivity-centred ideology can marginalise worker experiences (Welfare et al., 2019) brushing aside their imagined futures, and advocate technological progress even if it is at the expense of ecological sustainability. Against this we promote the importance bringing together diverse stakeholders, including both environmentalists and labour representatives, to reimagine routes forward that lie in the textures in-between utopic and dystopic extremes of the sociotechnical imaginary.

We offer the concepts of pedagogic and collaborative touch as a basis from which to explore alternative imaginaries further where 'human-centred' (Nahavandi, 2019; Welfare et al., 2019) industrial futures can be worked towards. This ethnographic study illustrates the utility of converging social perspectives of touch with the sociotechnical imaginary to centre humans whilst critically attending to the future. For example, the provocation of superhuman touch suggests that to promote such futures it is important that the development and integration of new technologies does not reinforce a binary *comparative-competitive frame, nor negatively impact on* the sociosensorial conditions of labour for workers. We contend that with the prospect of a new wave of industrial robotics, including tactile (tele)robots on the horizon heightening expectations, hopes and anxieties (Nam, 2019; Pawar et al., 2016; Zamalloa et al., 2017) it is essential to bring the social and technical into closer dialogue.

Critical social research has a central role in pushing back and creating alternative digital futures (Mager & Katzenbach, 2021) that can lead to "better futures" (Coleman, 2017; Pink, 2021) for industrial workers. The scope and scale of the study discussed in this article is limited by its attention to the imaginaries of manual laborers, industrial managers, and roboticists. Further work with a wider range of diverse stakeholders is needed to bring a broader range of perspectives and imaginaries into conversation. Nonetheless, the concepts and provocations discussed in this paper offer valuable starting points for dialogues to inform and strengthen the call for human-centred futures with tactile (tele)robots.

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