Responsible Innovation of Touchless Haptics: A Prospective Design Exploration in Social Interaction

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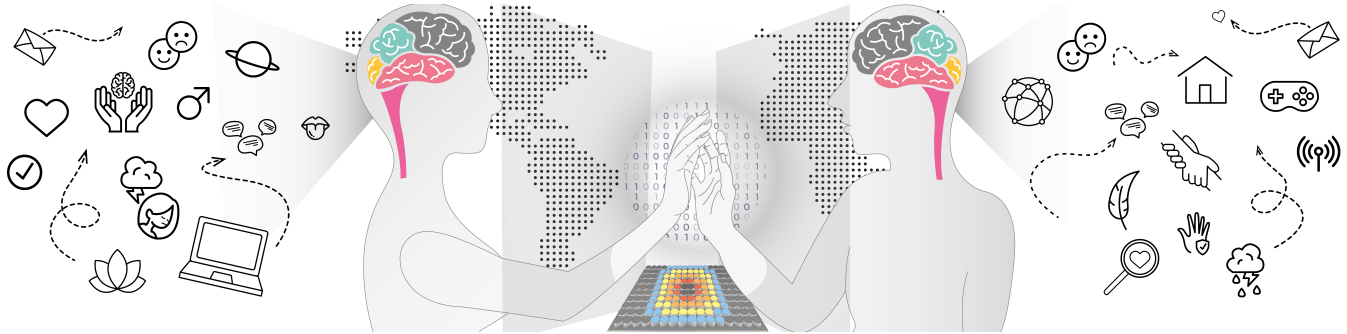[3]University of Copenhagen, Copenhagen, Denmark

Figure 1: Example of touchless social interaction. People can feel each other remotely, convey emotions through tactile communication and interact with systems without touching any surface physically.

ABSTRACT

The rapid development of touchless systems has introduced many innovations in social interaction scenarios in recent years. People now can interact with touchless systems in social applications that are aimed to be used in everyday situations in the future. This accelerated development makes us ask, what will the next generation of touchless systems be like? How can we responsibly develop new touchless technologies in the future? To answer the first question, we brought together 20 experts to ideate, speculate, and evaluate possible touchless applications for social interactions. A total of 48 ideas were generated from two consecutive workshops. Then, to answer the second question, we critically analyzed those ideas through a thematic analysis using a responsible innovation (RI) framework, and identified key ethical considerations to guide developers, practitioners when designing future touchless systems. We argue that the social scenarios described, and the RI framework proposed in this paper are a useful starting point for responsibly designing the next generation of touchless systems.

CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI)*; Empirical studies in HCI;

KEYWORDS

touchless interaction, mid-air haptics, ethics, responsible innovation, social interaction

1 INTRODUCTION

We live in a world that is increasingly characterized by a fusion of physical and digital/virtual events, in which touchless technology is being designed for application scenarios that are commonly found in our daily life and social interactions such as shops, hospitals, museums, and cars [63, 75, 92, 102]. Before the COVID-19 pandemic, the world hardly understood the importance of touchless technology. Today, "the average person can certainly appreciate the need for touchless interaction" [51], and yet it is unclear what role such interactions can and should play in the future. The consideration of responsible innovation (RI) becomes crucial considering the rapid development of touchless technology and its increasing relevance in social interaction scenarios.

With social scenarios, we refer to applications in which there are interpersonal, group, or institutional interactions achieved through digital touch technologies (e.g., social touch), that over time could make their way into everyday social situations through applications in different contexts, from home to workplace, educational and healthcare settings. Thus, social touchless interaction scenarios

enrich a wide range of research on haptic technologies and applications in the HCI community, and have the potential to enrich our reflections on post COVID-19 pandemic design considerations [87] especially from an expert-based perspective that opens up further avenues for prospective design explorations.

Moreover, awareness of ethical implications of novel technologies have widely emerged in the scientific and design community. For example, [3] introduced the three laws of robotics, as a fundamental framework to underpin the behavior of robots. Regulatory implications of robotic systems have been implemented in order to address the impact that robotics have on practice areas [48]. Legal systems have started crafting guidelines for autonomous vehicles [11] that preserve moral responsibility [27], as well as drafting theoretical foundations for the next generation of autonomous systems [45]. Yet, a RI landscape around the case of touchless technology in the context of social interactions remains unclear. Despite the growing development of mid-air interactions [104] and of ultrasound-based applications [85], we lack an understanding of the ethical considerations of this technology in social, work, design, and private interaction settings.

The development of ultrasound-based mid-air haptics has increased rapidly in the last few years. In 2008, we saw the first ultrasonic system able to make a person perceive tactile sensations in mid-air without the need of physical attachments [52]. This was followed by Carter et al. [21] in 2013, who proposed a system designed to provide multi-point haptic feedback. A few years later, the same principle was used in novel interaction paradigms previously only seen in sci-fi movies. For example, it is now possible to touch holograms [58, 86] as well as levitate objects [46] and interact with them [36, 81]. We can now interact with computers, digital objects, and other people in immersive 3D environments in which we not only see and hear but also touch/feel, and even smell and taste [24]. This technology is also able to convey information [10, 76] with potential for conveying emotions [38, 74]. Furthermore, it has become wearable [88] and not limited to hand feedback but also other body parts (e.g., the face [40] and the mouth [93]). Some of these features suggest potential for dynamic and more natural scenarios such as home environments [101], in-vehicle scenarios [61] and online shopping [59, 78], where people can naturally integrate touchless interactions during daily tasks. This quick advancement clearly augurs an even more accelerated development of this technology in the next few years which makes us ask, what should the next generation of touchless systems look like and what kinds of ethical issues might they bring about?

Previous work has reviewed existing ultrasound-based mid-air interactions [25, 60, 104] in practical design scenarios [25], as well as studied some responsible considerations around this technology, such as safety [29] and inclusivity [76]. However, they focus on a retrospective view of existing systems that makes it difficult for non-experts with touchless technology (research or practice community and end users) to imagine the next generation of touchless systems and therefore a prospective view is missing in the literature.

A prospective view is needed because RI tells us that we need to anticipate potential risks so that we can respond and adapt as technologies evolve. This means that designers, developers, and practitioners using emerging technology should anticipate expected and unexpected implications that introducing a new technology can produce in society. For example, the introduction of autonomous vehicles would require new street infrastructures and legal frameworks [11, 45], the introduction of social media saw an increase in cyberbullying [106] and concerns about privacy and surveillance, which in turn forced institutions to regulate digital content [79].

While it may be difficult to anticipate what and how touchless systems will affect society in the future, we have a responsibility to consider the consequences and to ensure its potential benefits and risks are distributed evenly. Speculative design [31] provides us with a way to envision what future touchless experiences could be like and to consider its possible risks. Responsible innovation allows us to consider these futures within the values and contexts of the present, enabling us to respond accordingly and to ensure that these emerging technologies are aligned as much as possible with the diverse needs of society. This has not yet been adequately explored for touchless systems, leaving open the question as to how best to align them with societal need.

To fill this gap, we collectively speculated about possible futures of touchless systems in social interaction scenarios and associated risks. We asked experts in ultrasound-based touchless systems, working actively in designing, developing, and evaluating this technology, how they imagine the next generation of touchless systems. To do so, we conducted two workshops with 20 experts from industry and academia with a variety of backgrounds such as computer science, HCI, physics, and cognitive sciences, to jointly ideate touchless experiences for applications in social interaction.

From analyzing a total of 48 ideas, we identify concepts that can describe how experts envision future touchless systems (sensory, emotional, entertaining, remote, and stored), the main social benefits highlighted by experts (connectiveness, wellbeing, and communication) as well as the principal critical responsibilities they raised (safety, acceptability, and privacy). We then brought an RI expert on board (with a broad expertise in applying and training various stakeholders on RI) to critically discuss and analyze the emerged ideas and experts' assumptions, in relation to RI principles: *anticipation*, *reflexivity*, *inclusivity*, and *responsiveness*. For example, we reflect upon questions such as what kind of social world is imagined? (*anticipation*), why is the technology being developed? (*reflexivity*), who it is imagined will benefit? (*inclusivity*) and how can we develop responsible touchless systems? (*responsiveness*).

Thus, our contribution is twofold, we first provide an empirical exploration of experts imagined future design directions of touchless systems, and we then present a critical thematic analysis of those directions through the lens of a RI framework. Combined, this work aims to stimulate a critical discussion and highlight responsible considerations when designing future touchless systems. We argue that the social scenarios proposed by the experts and the RI framework described in this paper are a necessary first step in reflecting upon the next generation of responsible touchless systems in the wider context of HCI touch technologies [87].

2 LITERATURE REVIEW

We first review existing RI frameworks considering emerging innovations and particularly used in HCI. Then, we review existing applications of ultrasound-based mid-air haptics in social interactions and highlight the need for a RI perspective for this technology.

2.1 RI Frameworks for Novel Technology

Science and technology play an important role in our everyday lives, shaping our societies in countless ways. It is this shaping, or ordering, of social life that is of interest to practitioners of RI. Whether consciously or not, societies choose certain technological pathways that influence how people work, communicate, travel, learn and relate to one another [53, 69, 108]. RI seeks to harness the power of scientific knowledge and technological applications in ways that make societies worth living in [34].

The RI framework [97] recognizes that innovation typically takes place within contexts of uncertainty and change in which we face a dilemma of control [23] whereby we lack the evidence required to predict the social impacts of specific technological pathways [26]. In place of prediction, RI proposes anticipation, where multiple ethical, societal, and cultural concerns are identified early in the innovation process and addressed openly and transparently [2]. To ensure that new technologies align with social values, we need to reflect on what kind of social worlds our innovations create and whether they are fair, equitable and inclusive [14, 28, 107]. This requires us to reflect on the values underpinning the work, invite dialogue with a diversity of stakeholders and communities, and provide scientists and engineers, both in academia and industry, with opportunities to respond and adapt objectives accordingly [2, 67, 100]. These four aspects of responsible innovation - anticipation, reflexivity, inclusion, and responsiveness - will be returned to in the discussion of the paper.

2.2 RI frameworks to Existing HCI Research

While scarce, there are efforts exploring the relations between HCI technology and RI. For exmaple, Bates et al. [8] explored an RI Agenda for HCI by building principles for innovators to think about social, environmental, and economic impacts of HCI in society. González-González et al. [41] analyzed the low representation of women in technology and presented different methodological approaches that allow for the inclusion of a gender perspective in HCI technology design. Yaghmaei [110] constructed a framework that provides a grounded conceptual path for managing and assessing RI principles in industry. Jirotka et al. [56] illustrated the need for a new approach for the governance of information and communications technology (ICT) and propose a framework including areas such as anticipate, reflect, engage, and act.

While some related works do not explicitly mention a RI framework, they still use anticipation and reflexible approaches to understand social, environmental, and economic impacts of innovations. For example, Bates & Hazas [7] quantified energy demand from home sensing installations and reflected on their environmental impacts. Sturdee et al. [98] reflected on considering unintended consequences of technology developments when submitting, reviewing, and publishing HCI work. They argue that researchers mostly expect positive consequences and therefore they speculated about negative impacts and encourage researchers for creative-yet-grounded speculation about technology future. Lindley et al. [64] explored what would actually imply to adopt the HCI technology in society and introduce reflections to better design, critique, and contribute to the future technology. Shilton [94] discuss values and ethics in HCI research and describes frameworks that attempt to move values-oriented design into everyday design settings. Muñoz-Arteaga et al. [73] suggest that HCI plays a key role into the design and development technology aimed to achieve sustainability and sustainable development.

This research also highlights anticipatory methods useful for considering RI principles within research, such as value-sensitive design – a method that accounts for human values throughout the design process [37], and design fiction - a speculative design method which focuses on building fictional worlds [16]. For example, Wu et al. [109] used design fiction to raise discussion on the social implications of new technologies in industry, which designs and implements new systems. Friedman et al. [37] analyzed various value sensitive design methods and provides reflections on core characteristics of value sensitive design methodology, and heuristics for innovation.

Many of these methods are deployed in RI work. RI uses a range of anticipatory, reflective, and engagement methods in order to respond, in the present, to the potential challenges that new technologies might pose. While future-orientated work is important, RI also values action in present in the form of regulations, policies, public and stakeholder engagement activities, training, and adaptation that might be collected under the banner of care work or an ongoing responsible 'culture' of innovation [42].

This recent and growing engagement of HCI researchers with RI and associated areas such as sustainability, environmental impact, and social values, provide the community with a growing set of guidelines and considerations to foster a culture of responsible innovators. We build on this prior work, contributing a particular perspective on emerging haptic technologies, especially touchless (i.e., mid-air touch) systems for social interaction scenarios, a topic with growing interest in a society where we have been deprived of touching each other due to the COVID-19 restrictions [87].

2.3 Social Mid-air Touch

Ultrasound mid-air haptics technology has been applied to a wide range of applications including automotive, location-based entertainment, digital out of home and XR [85]. An interesting aspect of this technology is its relation to affection and emotion. Affective touch can, through C-tactile afferents, evoke pleasant and social touch sensations when the skin is brush-stroked at an optimal speed [65]. It is currently disputed whether ultrasound can stimulate C-tactile afferent and achieve a similar effect [80, 99]. Whether C-Tactile afferents are stimulated, affective touch can be evoked through different mechanism. For instance, previous research has suggested that ultrasound targeting the palm can mediate emotions [74]. Additionally, Seinfeld et al. [91] recently reported that ultrasonic haptic feedback enhances the illusion of being affectively touched in a virtual environment compared to visual feedback alone. Touchless haptic stimulation has been suggested as one of the five new trends in the research on affective stimulation by triggering emotional reactions through mid-air touch [32]. Taking advantage of this effect, a number of applications involving social interaction have been proposed in the literature. For example, Makino et al. explored haptics transfer that enables mutual user interactions so that Users can mutually interact with each other in real-time [68].

While still in development, this technology has been envisioned to assist humans in application scenarios that are commonly found in our daily life and social interactions such as interactive displays in urban environments (e.g., shops, train stations and shopping malls) [63], museum exhibitions [102], in cars dashboards [92], in hospitals assisting surgery [75] and in calming social settings [66]. Additionally, with the recent covid-19 pandemic, mid-air haptics has been also suggested to be a promising solution to promote a touch-free and hygienic alternative to interact with technology (public displays, elevators) in social and public spaces [50, 95].

However, despite the growing applications of touchless systems in social scenarios, we still lack a RI view that starts from asking, what are the user needs? who will benefit? what are the possible risks of introduction a novel technique? In most of the cases, the introduction of novel touchless systems is based on innovation but not on anticipation, reflexivity, inclusivity, and responsiveness (i.e., a RI framework). In this paper, we address this limitation by first designing a speculative design exploration with experts to explore how they envision touchless systems in the future, followed by developing a framework for responsible touchless systems.

3 DESIGN EXPLORATION OF MID-AIR HAPTICS FOR SOCIAL INTERACTIONS

To explore social applications between users and touchless technology, we conducted two online workshops with 20 experts (3 females), currently working on touchless haptic technology from industry (6 participants) and academia (14 participants). Participants were distributed across four different countries (United Kingdom, Spain, Denmark and Ukraine) and selected as part of a cross-national research project (the Touchless EU Horizon 2020 project [83]) working on touchless technology for social interaction. This 4-year project involves experts both from academia and industry with skills from computer science, engineering, human-computer interaction, and neuroscience. Participants had an average experience of 5 years working with touchless haptics, and senior researchers with over 15 years of experience both in haptics and touch perception. Industry experts had an average experience of 6 years working on touchless haptics. With these different backgrounds on academia and industry, we aimed to raise different ethical perspectives arising from both technical and perceptual challenges.

Each workshop (one week apart) took place online using MS Teams and was divided into four groups of five participants. Each group included participants from mixed fields of expertise and at least one expert from industry and one senior researcher. Within each group, we randomly assigned a facilitator and a rapporteur who presented the final ideas to the plenary. Each workshop lasted 2 hours and started with a 15min introduction followed by separate group work in four breakout rooms (5 participants/group) for 1 hour, followed by a 40min general discussion with all participants.

3.1 Method

Participants were asked to adopt three thinking styles following the Disney's creative strategy [6] to propose ideas on touchless social interaction. We selected this method as its structure is easy to engage with for people not familiar with design thinking. This strategy has been used to fuel innovation and creativity providing
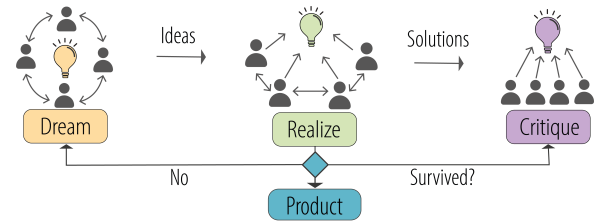

Figure 2: In the workshops, participants took on three roles adopted from [6]to speculate about future touchless haptics applications in social interaction scenarios.

an effective roadmap for the incubation of many products and projects for 30 years [30].

As shown in Figure 2, it consists of three different roles – the dreamer, the realist, and the critic. In the first thinking style, the group thinks as dreamers. The dreamer is not restrained by limitations or rules of the real world but generates as many ideas as possible and does not think about the obstacles on the way of their implementation. In the next style, the group adopts a realizer viewpoint which acts as pragmatic realists and use convergent thinking to review the ideas left by the dreamers. The realist is the manager who can convert a vague idea into a solution. The realist has no idea about criticism. The final style is the critic. In this role, critics analyze risks and care about the safety and risks of proposed solutions. The critic does not touch bare ideas but works with solutions only with the goal to help and foresee potential issues in advance. As shown in Figure 3, in the first workshop, participants focused on dreaming and realizing while in the second workshop, they focused on realizing and critiquing. Experts adopted a realist role in both workshops to ease the transition between both parts to recall what they discussed in the prior session.

3.2 Workshop 1

The first workshop started with a brief introduction explaining the agenda, followed by an ice breaker activity where participants showed an object (they were asked to prepare this object in advance) that they associate with touch interaction. Then, the participants were split into four groups of five members. During the group work, participants were asked to propose as many ideas as possible in which they imagine social applications between users and touchless technology adopting a dreamer role for 15min. After they finish the dreamer role, participants were asked to switch to the realist role for 20min in which they delimit to three ideas while thinking on solutions to the ideas. Finally, the rapporteur presented the top-three ideas (based on a collaborative choice amongst each group members) to the plenary session (40min) with all participants for general discussion.

3.3 Workshop 2

During the group work of the second workshop (one week after the first), participants further developed the top-three ideas proposed during the dreamer's role. To do so, they were asked to adopt the realist role for 15min in which they focused on solutions, followed by the critic role for 20min in which they focused
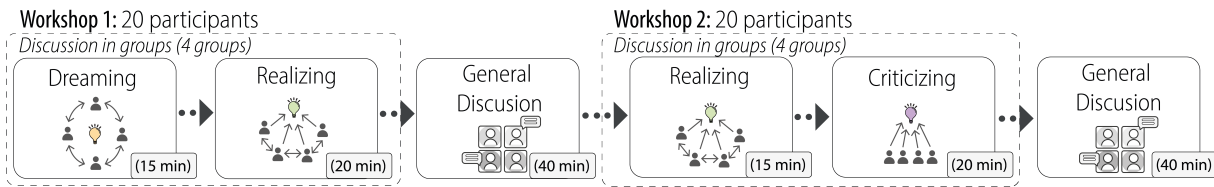
Figure 3: Procedure followed during the two workshops which took place one week apart and involved a total of 20 participants.
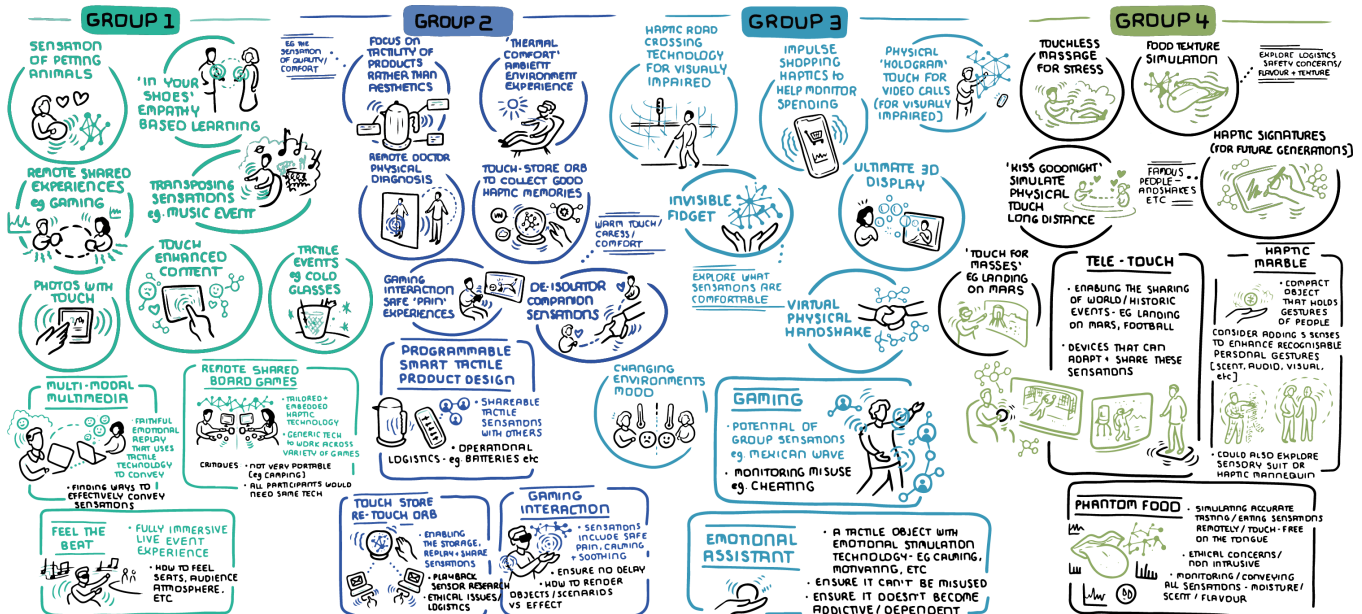

Figure 4: Ideas proposed by experts. A professional illustrator captured the different ideas while experts where discussing.

on identifying constraints and challenges of the ideas. Finally, the rapporteur presented the final top-three ideas (with their solutions and critics) during the general discussion with all the participants. Finally, while rapporteurs were presenting the final top-three ideas during the general discussion, all participants were asked to rate them in terms of desirability in a scale from 1 (not desirable) to 5 (extremely desirable) using the Poly feature of Teams. Participants were then asked to rate offline (after the workshop finalized) the feasibility of the final top-three ideas in a scale from 1 (feasible now) to 5 (futuristic). We explored desirability and feasibility as we were interested in knowing how experts, currently developing the technology, evaluate what is possible/desirable and when.

4 RESULTS AND ANALYSIS

We aim to answer two interconnected questions. The first, "how do experts imagine the next generation of touchless system for social interaction?" was addressed in the workshops. Participants did not have to reflect on how to responsibly develop ideas, but were guided by the 3 roles - dreamer, realist, and critic, described above. We then analyzed the ideas using an RI framework guided by the second question "how can we responsibly develop new touchless technologies?" which was led by an RI expert.

All sessions were video recorded, and transcriptions were obtained from autogenerated subtitles. The data analysis consisted of two main parts. (1) To answer our first question, we extracted relevant concepts and conducted a co-occurrence analysis [43]. (2) To answer our second question, we conducted a thematic analysis using the responsible innovation framework by Stilgoe et al. [97] to extract relevant ethical considerations from the different ideas. The first author analyzed the transcripts and organized 2 rounds of discussions, then the second author (RI expert) did another analysis with further 2 rounds of discussion.

4.1 Extraction of concepts

Figure 4 shows an overview of a total of 48 ideas proposed by participants captured by an illustrator during both workshops. From those ideas, we extracted relevant factors from the experts' discussion while they were dreaming, realizing, and criticizing. Figure 5 shows the top-three ideas from each group (an extended table with all the ideas can be found in the supplementary material). Figure 6 shows the ratings from participants in terms of desirability and feasibility of the top-three ideas. The factors we extracted from all the ideas are the following.

	Dreaming			Realising		Criticising	Interaction type			
Idea	Aim	Social benefits	Novelty	Challenges	Responsibilities	How	Who	Where	Cross-idea concepts
Remote shared experiences	Share gaming experiences. Game-user feedback (poking when attacked) and user-user feedback (physiological signals)	-Empathy -Bonding	Emotion as potential type of feedback	-Human experience monitoring (sensing)	Safety	Shared	-Friends -Relatives	-At home	-Gaming -Emotion -Remote
Feel the beat	Crossmodal sensations for sensory substitution (music to touch, volume to heath, map musicians' feelings)	-Inclusivity -Equity	Emotion as potential type of feedback	-Sensing and delivery	Disability	Shared	Musicians -Artists -Audience	-At theatres -Concerts	-Emotion -Sensory
Touch-enhanced content	Share digital content with touch patterns to convey emotions (e.g., photos with touch, emails with touch)	-Connectiveness -Bonding	Capture touch and convey them via digital content (touch emojis)	-Delivery -Perceptual -Sentiment analysis to translate text into touch	Privacy	Shared	-Friends -Relatives -Partners	-At home -At work	-Emotion -Remote -Stored
Touch-store-re-touch orb	Social touch stored in a magic orb (a touch-drive). People can replay it or send it to someone else to open, run, and feel.	-Communication -Inclusivity	-Encapsulating haptics	-Sensing and data format -Create a vocabulary of touch sensations	Safety	Shared	-Anyone	Anywhere	-Sensory -Stored -Emotion
Game interaction	Realist experiences of gaming such as feeling the pain or sense of healing when they are hurt or healed in the game.	-Entertainment	Pain as a type of feedback	-Identify body locations -Determine safe level of pain -Understand healing sensations	Safety	Individual	-Gamers	-At home	-Sensory -Gaming -Emotion
Smart product design	Product enhancement through tactile patterns leveraging the attachment and familiarity that people feel towards objects.	-Marketing	Using attachment to objects to recreate sensations that enhance product design	-Embeddable tactile displays -Understand touch that make experiences more enjoyable -How to measure attachment to objects?	Safety	Individual	Customer	-At shops -At home	-Sensory -Emotion
Emotional assistant	Help users regulate their impulses that negatively impact their wellbeing, or help them manage external stress	-Wellbeing	Mid-air haptics for wellbeing	-Delivery -Perceptual	Safety Acceptability	Individual	General people	-At home -At work	-Emotion
Virtual handshake	'Tangible' handshake through the phone	-Connectiveness	Rendering of complex textures	Rendering	Safety	Shared	General people	-At home -At work	-Sensory -Emotion -Remote
Gaming	Augment physical interaction in virtual games (foul, shoulder bump, celebration hug). Like in Ready Player One	-Bonding	Create attachment between players via haptics	-Delivery -Perceptual -Understanding gaming behaviours	Safety Acceptability	Shared	Gamers	-At home	-Sensory -Emotion -Remote
Teletouch	Share haptic experiences with an audience to increase engagement	-Entertainment	Shared touch experiences with the masses	-Latency -Simplification of sensations -Location of sensors	Safety Acceptability	Individual	-General public	-At home -Theatre -Classroom	-Sensory
Phantom food	Stimulate gustatory experiences on the tongue trough mid-air haptics	-Marketing	The creation of digital taste via ultrasound	Understanding locations and patterns that create taste perception	Safety Medical	Individual	-General public	-At home -Restaurant	-Sensory
Haptic marble	Haptic patterns of a person are stored (e.g., in a portrait) which can be reproduced after the person has died	-Communication	Storing and replaying haptics	-Replicating a person's specific signature (a hug). -Storing a person's haptic patterns	Acceptability Privacy	Shared	-Dead people -Famous people -Family	-At home -Museums -On the go	-Sensory

Figure 5: Top-three ideas from each of the four groups in the workshops (from a total of 48 ideas) and the factors we extracted while experts were dreaming, realizing, and criticizing

- The aim of the idea: To understand the problem that the technology addresses and the beneficiaries of the solutions (extracted during the dreamer role).
- Social benefits: To understand the needs and the positive impact the technology can bring to society.
- Novelty: In light of the accelerated development of mid-air haptics, this factor extracted the novelty of the ideas during the realist role.
- Challenges: To understand the feasibility of the ideas that experts envision in the future and how soon they think can be brought to life (easily done or futuristic). This factor was extracted during the realist role.
- Responsibilities: Since our exploration aims to identify ethical consideration for future touchless systems, we extracted RI factors that experts found relevant in each idea during the critic role.

- How: To understand whether the experience is individual or shared with others.
- Who: Since all the ideas involve social scenarios, we were interested in extracting the identities of people involved in the interaction.
- Where: To understand where the interaction between people and touchless system occurs. The factors how, who and where were extracted from all roles.
- Cross-idea concepts: We extracted relevant concepts that were more frequently used in the different roles. These concepts were shared between different groups, and we argue that can be a starting point to answer the question: how touchless system should be in the future?.
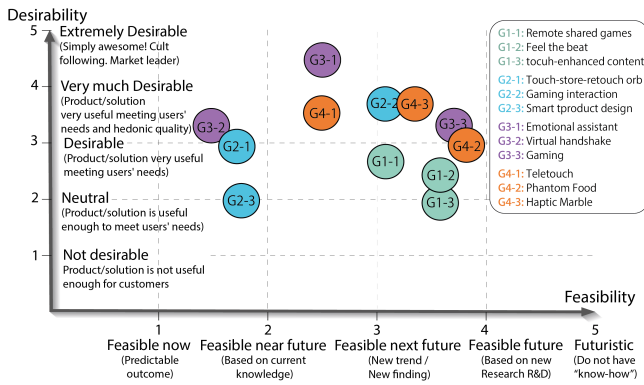
Figure 6: Plot of desirability vs feasibility of the top-three ideas from each group.

4.2 Analysis: How do experts imagine the next generation of touchless system for social interaction?

We noted that experts largely ideated innovations producing shared experiences (60%), while some ideas included individual experiences (e.g., an anemo-massage and a space suit), most of them were based on connecting people and producing empathy between users. We mainly analyze the social benefits and critical responsibilities raised by experts (illustrated in Figure 7b-c).

The social benefit most frequently brought by experts was connectiveness (23%). For example, remote shared games, virtual handshakes, virtual dating, and touch-based phone calls were ideas addressing issues of isolation (e.g., during lockdown, while in prison, people in hospitals). This suggests that experts see digital touch with a great potential to convey touch experiences when these cannot be provided physically and therefore promote a sense of closeness. Wellbeing was also a frequent social benefit raised by experts (17%). Ideas like virtual petting, mood modulation, remote medical appointments, and mid-air haptics producing relaxing sensation were ideas to address stress and anxiety. Similarly, experts raised communication as a social benefit (13%) with ideas such as a touch dictionary, sending touch patterns through email and phone calls and conveying information through touch for sensory substitution (e.g., deaf people could feel music).

Furthermore, the most frequent responsibilities identified by participants were safety (39%), acceptability (24%), and privacy (19%). Experts raised the idea of providing realistic mid-air haptic feedback in gaming experiences in which the user can feel pain and healing sensations. However, since the effects of ultrasound exposure are not fully understood [9], experts pointed out that ultrasound projected onto the user's skin must be safe and carefully regulated for future applications (e.g., regulating intensity, exposure time and understanding pain thresholds). Experts also highlighted that some innovations can be difficult to accept. For example, the idea of a digital goodnight kiss is an experience that one might want or avoid depending on the sender. In another example, ultrasound stimulation on the tongue could require that the user has their tongue exposed which could be considered unacceptable for some people. Therefore, experts established that studies to determine the
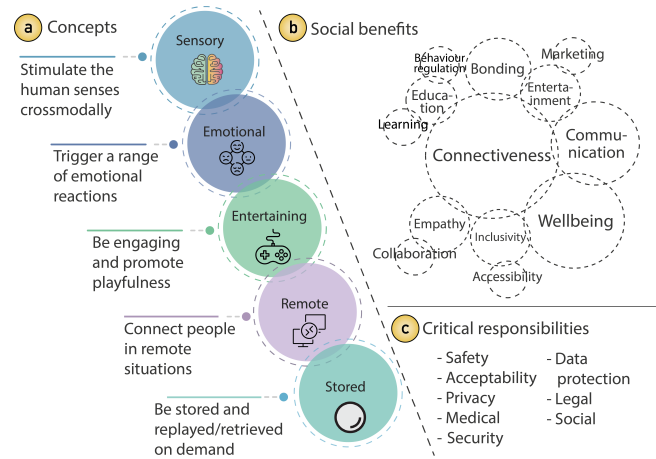
Figure 7: Conceptual map illustrating the cross-idea concepts on how experts envision touchless systems in the future (a), social benefits (b) (the bubbles size represent the frequency), and the critical responsibilities highlighted by experts (c).

acceptability of such touchless interactions need to be conducted for future applications. Privacy was also a point of discussion since touch experiences could be intrusive. For example, if a person suddenly activates your camera to see you without your knowledge, it would be disrupting your privacy. The same should be true for shared touch experiences. For example, the user must have full control of any tactile experience they receive and be able to regulate the haptic device activation.

We were also interested in exploring how feasible and desirable experts find the top-three ideas (see Figure 6). From the top-three ideas, we observed that participants considered some innovation feasible in near future (i.e., based on current knowledge) such as touch-enhanced content and virtual handshakes, which could be achieved through current development of mid-air haptics rendering. Some ideas were considered feasible in the next future (i.e., based on new research) such as creating taste sensation on the tongue through ultrasound stimulation. However, no idea was considered as too futuristic. Moreover, in terms of desirability, experts considered ideas focused on wellbeing as more desirable (e.g., an emotional assistance to manage anxiety) while entertainment-based ideas such as touch-enhanced content were considered less desirable.

Considering the social benefits and critical responsibilities identified by experts, we particularly noted five cross-idea concepts we argue that could describe how experts envision the next generation of touchless systems. These concepts were determined using an inductive approach by the first author with agreement with other two researchers in the team after several iterations. We describe them below and illustrated them in Figure 7a.

- **Sensory**: The digital touch experience should stimulate the user's senses crossmodally. Experiences from one sense (e.g., sound) could be transferred to another (e.g., touch). For example, experts pointed out that mid-air haptic feedback could be provided to deaf people in a concert to convey music patterns in form of tactile patterns.

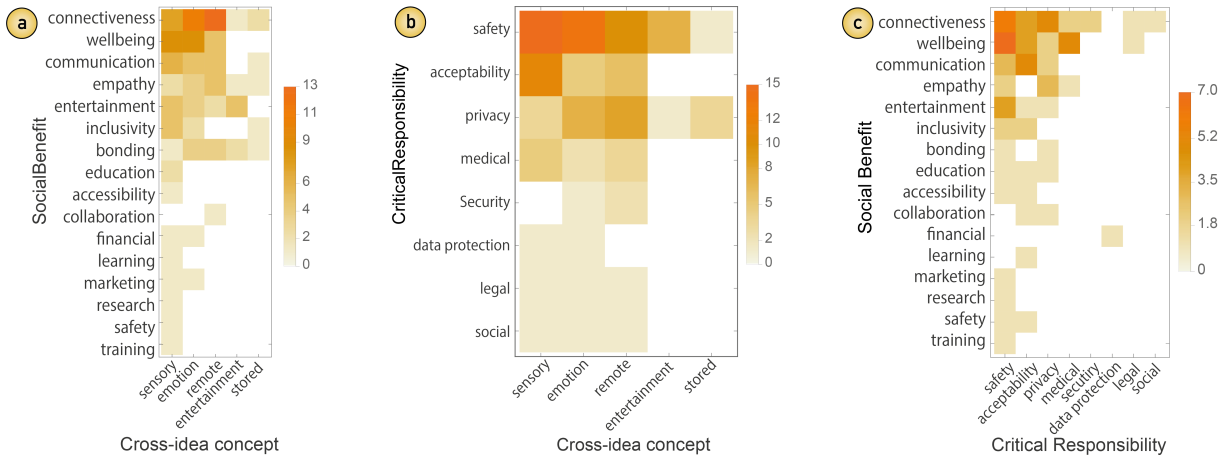**Figure 8: Heat map illustrating the co-occurrence of cross-idea concepts between social benefits (a) and critical responsibilities (b) as well as the co-occurrence between social benefits and critical responsibilities (c).**

- Emotion: Touchless experiences should trigger a range of emotional reactions. Experts envision future application in which touchless systems trigger positive emotions such as feeling a virtual kiss or a virtual handshake to promote wellbeing and enjoyment. However, they think experiences should include negative emotions as well to promote realism such as replicating pain sensations in video games.

- Entertainment: The touchless experience should be engaging and promote playfulness. Experts proposed many ideas around entertainment such as touch-enhanced media (e.g., photos with mid-air touch) and gaming experiences that enable sensations such as shoulder bump, or celebration hugs.

- Remote: The touchless experience should connect people in remote situations bringing 'physical' touch sensation where these cannot be provided. Experts envision applications in which touch is shared from distance and promote empathy to the receiver. For example, "teletouch" able to share individual tactile experiences to an audience (e.g., the sensation of landing on mars) or a single person (e.g., share my pain to my doctor for better diagnosis).

- Stored: Experts see a touchless experience as something that can be physically or digitally stored and replayed/retrieved on demand. They proposed the idea of storing peoples' signature. For example, store my partner's hug and replay it any time I want, or buying Michel Jackson's handshake and share it with my friends (similarly I would do with a photo).

Additionally, from the extracted features (5 cross-idea concepts, social benefits, and critical responsibilities), we conducted a co-occurrence analysis [43] to identify the relationship between these features. As shown in Figure 8, we found that the social benefit of connectiveness and the cross-idea concept remote co-occur most frequently (a). The critical responsibility safety and the cross-idea concept sensory co-occur most frequently (b). Finally, the social benefit of wellbeing and the critical responsibility of safety co-occur most frequently (c).

These cross-sectional insights presented in Figure 8 reveal trends in both the experts thought process, as they proposed, analyzed, and reflected on the different ideas, but also in the ideas themselves. The co-occurrence analysis exposes commonalities in associated challenges, responsibilities, and considerations, while highlighting where and what kind of further research and development might be needed.

4.3 Thematic Analysis through the lens of RI

Having grouped and coded the workshop data descriptively (see Figure 5), we submitted the data to a thematic analysis which was conducted by RI expert (second author of this paper) who was invited at the analysis phase of the research. A thematic analysis describes a form of qualitative analysis which seeks to group together data according to patterns that are meaningful to the researcher in relation to the research question [18]. This research seeks to develop a framework for responsible touch, asking how can novel touchless technologies be developed responsibly?

We apply a reflexive thematic analysis which refers to "an inherently subjective process" [19], whereby themes are generated by the researcher in relationship with the data. Our interpretive framework is largely drawn from Stilgoe et al.'s framework for RI [96] and cultural and social studies of haptics and touch [22, 54, 77, 84]. We worked in an iterative and recursive fashion between the data from the workshop (inductive) and the above-mentioned concepts and theories (deductive), whereby "existing research and theory provide the lens through which we analyze and interpret data" [20]. This was done in a phased manner, from initial coding and generation of initial themes, to the generation of final themes and their further analysis according to the literature [19].

Given that responsibility is an interpretative concept without a single, definitive meaning, we are granted a certain latitude in how we identify meaningful patterns within the data. Our understanding of responsibility is drawn from existing literature from the field of RI [96]. This flexibility in interpretation is important - RI assumes

that new technologies emerge from complex systems within contexts of unpredictability and change. It also holds that there are multiple perspectives on the meaning of responsibility that need to be considered. With this in mind, an interpretative, qualitative approach is best suited in that it can accommodate uncertainty, ambivalence, while holding open a space for future critique.

In short, our approach aims to identify some aspects of responsibility, from one perspective, holding open the possibility that there are other important dimensions to touchless responsibility that may become relevant at a later date. Having said that, in the next sections we describe four themes that we identify and discuss in relation to the RI framework which emphasizes anticipation, reflexivity, inclusivity, and responsiveness. Finally, when we use the term "identify", we do not wish to claim that the patterns that have been identified exist, unmediated, in the dataset. Rather, we use it in a relational sense, to indicate the correspondence between our research questions (and theoretical dispositions) and the patterns that emerged in the data through this relationship.

4.3.1 Reduction of complex psychosocial experiences to digital touch sensations. The broad pattern that was established was a sense that complex psychosocial experiences could be reduced to digital touch sensations. We can see this in the view that intimate emotions could be shared between friends and family.

Group 1 – Idea 2 *"I just want to send emails with touch or instant messages sent to my girlfriend with embedded touch information like holding hands or caressing your forearm".*

There is a tension, here, between a positivist interpretation of emotion as something which can be codified and transported, largely intact, between individuals, and emotion as what Margaret Wetherell describes - "often unarticulated and inchoate senses of the pattern in a relation or in a situation, part of the affective-volitional stream of everyday life that moves us [...] to one end or another" [105]. From this latter view, emotional experiences are never comparable between bodies, precisely because they take place in different bodies, with different subjectivities, and experiences. A hug for a sexual abuse survivor may be experienced very differently from someone who has not undergone such trauma.

The workshop data also suggested that emotion and touch are interchangeable. Closeness, companionship, and empathy are all described as being achievable through digital touch applications.

Group 4 – Idea 32 *"We have distant relatives, people in the hospital, prisoners, maybe we just send a sort of tactile experience just to tell them we are thinking about them, so they don't feel alone".*

Group 2 – Idea 4 *"...provide some kind of feeling of companion or you have some partnership, like holding hands [...] probably for terminally that could feel alone in a hospital".*

Another application that is imagined, is the ability to control habits and impulses through haptic technologies.

Group 3 – Idea 21 *"... there's another situation where I've just received my salary, and the app is giving me tactile sensations which encourages me to buy that expensive outdoor furniture...".*

Again, this envisions habit or impulse as a problem of information transfer, whereby the individual simply needs to be provided with the appropriate data to correct their behavior (preventing/encouraging to spending money). This does not account for the possibility that people behave irrationally or in ways that are fully

accessible to our consciousness subjectivity [12]. We might also consider some of the applications where sensations are imagined to be translatable cross-modally. This has been a longstanding dream for haptics researchers, whereby experiences from one sense (e.g., vision) could be transferred to another (e.g., touch) [77]. Scholarship on the conceptualization of touch in VR has been critical of the "body as machine" metaphor for dehumanizing people and creating a "functional view of touch" [82].

Group 1 – Idea 7 *"We can transpose modalities in a way, maybe I can convey music features through other channels of touch or emotion".*

As well as being shaped by psychological factors, experiences of touch might differ according to social or cultural influences. This psychosocial perspective is defined by Hoggett [47] as "subjective experience in its social context [...] the constant two-way traffic between the private experience of the individual, their inner conversations, fantasies, dreams and feelings, and the world of family, work, leisure, culture, politics". The discussion will consider how this view problematizes the positivist conception of emotion as an easily identifiable experience that can be located, codified, and translated through haptic technologies.

The experts in the workshop also imagine that digital touch sensations can stand-in for, or replace people, objects, relationships. Participants suggest that this technology could replicate the experience of touching premature babies, distant partners, or incarcerated family members. We might consider other digital replacements for social connections such as smartphones and how successful they have been at improving social life. One often-cited reason for developing research in haptic technologies is to recapture touch in an increasingly digital social world.

Group 1 – Idea 4 *"A dating immersive app [...] when you can't meet the people you want, and have those kinds of feelings of closeness to the people but with an app".*

Group 4 – Idea 2 *"If you are distant from your wife or girlfriend or somebody else, and then you can just kiss and good night through your phone [...] this is partner interactions".*

4.3.2 All applications are assumed to have benefits. For this theme, novelty and benefit have been brought together, drawing attention to the tendency in the workshops to assume that all applications will have benefits. An important question for responsible innovation is to reflect on why we are doing innovation in the first place. Are we developing technologies simply because we can, thus ending up with solutions in search of problems? Quite often resources go into researching and identifying technical problems with less attention paid to identifying or learning about the social problems that these innovations might address. This can lead to situations where innovation is pursued as an end in itself. In the absence of a concrete social context within which these technologies can be used, a belief can develop in which the technology is capable of anything. We can see this in the workshop data where mid-air haptics imagined as being able to improve performance and wellbeing, substitute for other senses, regulate impulses, bring distant people together, share experiences such as landing on Mars. This can lead to hype or to fantasies of "technofixes", where complex social problems are imagined as having simple technical solutions.

Group 1 – Idea 1 *"Space suit [..], you can feel the rocks, the sun, the air, the temperature of the moon or other planet…"*

This danger can be reproduced in the very act of speculative design itself, where it can sometimes be assumed that technologies will exist in the future [64] in more or less acceptable forms. In these cases, speculative design becomes guilty of following too closely the definitions of technological novelty given to them by innovators. This can lead to a situation where undue attention is paid to over-hyped areas of research, raising the profile of the innovations that they seek to critique. Birhane and van Dijk [15] make this point in relation to AI, where, they argue, scarce philosophical resources are used to speculate on the moral status of imaginary sentient robots from the future while AI applications such as facial recognition or autonomous weapons are causing harms to real people in the present. RI attempts to critically examine questions about benefits and risks without paying undue attention to the hyped-up claims of engineers and innovators.

4.3.3 Risks do not include social values. The next broad theme drawn from the data relates to the risks of new haptic technologies, as outlined in the workshops. Here, the risks are largely characterized as technical challenges that need to be overcome. This can lend a sense of inevitability about the development of the technology. Once the technical challenge is solved, the innovation can proceed.

Group 2 – Idea 8 *"We want some optimized protocol to enable a cero delay transmission."*

Group 1 – Idea 8 *"The stimulation would have to be quite strong to really add a value […], I think the tradeoff between having a strong and salient haptic experiences and device safety is quite a problem."*

RI in contrast, attends to the social and cultural contexts within which new technologies are developed and implemented. Quite often there are many diverging perspectives on the risks and benefits of innovations that overflow narrow technical challenges. These include issues around governance, control, ownership. Social studies of new technologies also consider the role that power can play in how new technologies are rolled out. This involves questions of safety, accessibility, sustainability, inclusion, and exclusion, and how risks and harms are distributed. When we consider that barely any technology we can think of is currently available across the world, it is important to identify who will have access to new technologies, who they will benefit, and who they may harm. It is important to note an exception in the data for acceptability. This came up a number of times and can be broadly interpreted as how acceptable new haptics technologies might be. The question remains, however, who decides whether it is acceptable or not?

Group 4 – Idea 16 *"My critique is that, how would be the typical position to receive this [ultrasound stimulation on the user's tongue], would it be all the time with your tongue sticking out, that's not socially accepted…"*

4.3.4 Who is imagined? This last question encompasses the final theme - who? While a list of stakeholders was included (humans, animals, students, teachers, artists, doctors, families, and gamers), the list of impacted communities is quite narrow and not distinguished by the kinds of social groups that prior analyses have shown to be typically disproportionately affected by the risks and benefits of new technologies. This distribution conventionally follows the familiar political fault lines of race, gender, wealth, geography, and

age. Overall, these themes demonstrate areas where we can begin to think about the dimension of responsibility as it applies to novel touchless technologies.

4.4 Discussion: How can we responsibly develop new touchless technologies?

Next, we attempt to discuss the four themes in relation to the RI framework which emphasizes *anticipation*, *reflexivity*, *inclusivity*, and *responsiveness*.

Anticipation: If we consider *anticipation* to be "the attempt to describe and analyze the potential impacts, intended or otherwise (e.g., economic, social, environmental), that might arise from the outcomes of the research" [2] then a responsible approach to developing new haptic technologies will involve exploring both the anticipated and unanticipated potential impacts. The data analyzed earlier gives us a sense of the kinds of issues which may arise in the development of touchless innovation.

We might ask: what kind of social world is imagined by haptics experts when they design new touchless technologies? This data suggests that they imagine a world in which complex psychosocial relationships can be codified and digitized in such a way as to replace people, objects, memories, and experiences with digital touch sensations. What kinds of impacts might we anticipate in this context? For one, abstracting and quantifying touch, emotion, and human relationships and experiences empties these phenomena of the complex subjective, semiotic, and cultural dimensions. In short, there is a danger of "severing touch from centuries of accumulated associations and memories" [77].

In simple terms, *anticipation* is about asking "what if?" questions [97]. For example, we might ask, what if touchless systems develop that much, that digital touch becomes reliable enough to actually replace people and relationships? Such scenario could have potential implications in a variety of areas. For instance, what kind of legal regulations would apply for mid-air touch-based virtual dating? How would digital touch impact in sexual harassment in online communications [13]? There are already studies exploring sexual harassment resulting from touch-based haptic communication [72] and virtual dating [4]. However, since touchless applications are contactless (no controllers or actuators are used), how regulations can be different from contact-based applications (e.g., vibrational feedback on social virtual worlds [35].

Anticipation can be explored through a variety of more or less structured formats such as anticipatory governance [5], constructive technology assessment [89], horizon scanning [90], foresight [2], speculative design [57], and fiction-oriented scenario planning [70], but it is important to retain an open and exploratory attitude when doing so in keeping with the acknowledgement that innovation takes place within a context of uncertainty and unpredictability.

Reflexivity: Reflecting critically on the values underpinning new touchless technologies can help us to ensure that what matters to us is also what matters to wider society. As the above data suggests, experts in this space imagine a range of benefits for novel touchless technologies. The underlying social problems that these innovations are seen to address are largely in the fields of leisure

and entertainment as well as in replacing missing or distant people, objects, and experiences. Critically reflecting on these values involves thinking about whose values they are and who else might have something to say about these new technologies.

Reflexivity is about asking "why?" questions and can push us to confront some of the assumptions that sit at the heart of our work. Do we unproblematically assume that emotions are experienced in the same way by different people, regardless of gender, race, or personal experience? If we understand complex social problems such as loneliness in technical terms, do we miss the important cultural and political dimensions of the issue in our search for technical answers? *Reflexivity* encourages us to broaden our understanding of social contexts within which innovations take place, recognizing that innovation happens in sociotechnical systems and that these systems involve many stakeholders who might have something to say about our work.

We can reflect on the different ideas that experts proposed during the workshops. They envisioned touchless mass experiences shared to a large audience. For example, share relevant moments experienced by a single person with the mases (e.g., the tactile sensation of an astronaut landing on Mars for the first time). They also envisioned tongue stimulation through ultrasound to produce flavor experiences digitally (e.g., "eat" a virtual meal in VR). For these scenarios, one might ask why is this technology been developed? What are the problems such applications solve? We recall that RI encourages us to question our work and go beyond developing technology simply because we can and to deepen the needs of society when we develop applications. Since touchless systems are relatively a new technology it could be difficult to use [39]. For example, it could be difficult to generalize that this technology will be desirable for the masses. Moreover, people might find mid-air haptic stimulation invasive for certain applications (receive ultrasound stimulation on their tongue). Therefore, we need to see beyond the technical challenges we need to overcome to achieve such scenarios, but also think of social challenges it would imply such as acceptability of the technology.

Inclusivity: It is not enough for us to imagine what the benefits and risks of novel touchless technologies might be. We need to open up dialogue with the stakeholders, users, and communities who will actually be impacted by them to learn what their perspectives are. This requires us to consider who should be involved in developing touchless technology. One of the imagined applications from the workshops was the development of a "touch dictionary" and "vocabulary of touch sensations". These are powerful applications - imagine that one institution or individual could control how words in a linguistic dictionary were defined. In a democracy, we would hope that something as powerful - as potentially valuable - as this, would be arrived at in a shared and deliberative manner.

Inclusivity is thus about asking the "who?" questions. Thinking beyond the immediate users or conventional stakeholders that we might be familiar with to consider who else might benefit from our work. Does an emphasis on gaming, leisure and entertainment imagine wealthier users when there might be marginalized or underserved communities that might also benefit from novel touchless technologies?

During the workshop, experts envisioned scenarios benefiting users with sensory disabilities such as deaf or blind people (e.g.,

allowing a deaf person to "feel" sounds or augmenting accessibility cues on traffic lights with a mid-air haptic feedback). We see already efforts in the literature towards inclusivity using touchless systems, particularly in the area of disability, such as mid-air haptic braille applications [76] and attempts for sensory substitution in which one can feel art [102] or communicate science [44] via mid-air haptic feedback. Future applications should point towards the possibility to benefit other communities. This can only be achieved through robust co-creation practices where diverse publics and stakeholders participate in the identification and framing of risks and benefits upstream in the innovation process. Ethical investigations about the future of mid-air haptic technologies will require diverse perspectives if they are to be effective. The gendered nature of harassment and virtual groping in the Metaverse, for example, demonstrates how important it is that ethical perspectives reflect diverse lived experiences [33].

Responsiveness: While *anticipation*, *reflexivity*, and *inclusivity* are important, they are meaningless unless we are genuinely committed to responding to what we have learned [2]. Innovators who remain open, adaptable, and flexible are best placed to behave in ethical and socially responsible ways. These workshops have indicated that there is scope for including a more diverse range of perspectives in how the future of touchless systems is imagined. This can only improve innovation, as new problems, applications, research questions, and uses for touchless technologies are identified.

Responsiveness is about the "how?" questions. How can the insights from anticipation, reflection, and inclusion align our technical capacities and resources with the needs of diverse social groups? What concrete steps can be put in place to ensure that future research avoids harms and produces benefits that are fairly and equitably distributed? From this perspective, innovation is fundamentally a shared enterprise - co-produced across a range of experts and stakeholders. It flexibly navigates the uncertainty of complex sociotechnical systems while creatively problem solving in ways that are fair, just, and equitable. That is, through anticipating unexpected consequences, reflecting on the purpose of the technology, and including a wide range of communities, we can take action to start crafting the regulations and frameworks that future touchless systems would require. Such solutions should be responsive to new knowledge as this emerges. Further, since contactless stimulation is new compared with a wide range of contact-based technology and typical contact-based haptic systems stimulation, solutions should be responsive to emerging perspectives, views, and norms. For example, regulating how new touchless applications relate to intimacy touch [62].

Similar responsive approaches have been used in different areas such as regulating cyberbullying due to the introduction of mass social media [79], regulations of robot behavior [48], and regulating the ethics of AI [17]. Now we have the responsibility to design responsible touchless systems that account for the social values and benefit society.

5 DISCUSSION

While it may be difficult to anticipate what and how touchless systems will look like and affect society, especially in social interaction scenarios in the future, we started exploring this design

space anchored in a todays' emerging technology (mid-air haptics) that extends other HCI haptic technologies. In this paper, we first explored how experts imagine the next generation of touchless system for social interaction, grounded in their expertise of current functionalities and judgement of technical feasibilities. The outcome from this ideation process was then, in a second step, critically analyzed and reflected upon from a RI perspective, guided by the question how can we responsibly develop new touchless technologies?

From our first analysis, we can conclude that, in the future, experts imagine touchless social interactions in which complex psychosocial relationships can be codified and digitized in such a way as to replace people, objects, memories, and experiences with digital touch sensations. We then applied a RI lens to critically analyze this experts' view. For example, while engineers might be concerned about developing stimulus that are strong enough to give compelling gaming experiences, with low latency so that the experience is not disrupted or frustrating, they should start by considering that touchless experiences take place in different bodies, with different subjectivities, and experiences. Would all people perceive the same strength or speed of the stimulus? In another example, before innovating strategies around conveying emotions via digital touch, designers and developers should also consider cultural and experiential discrepancies of emotion perception between communities. How do we design a touchless experience that is suitable for sexual abuser survivors or autistic people?

It is important that we recognize that innovation happens in sociotechnical systems that involve many stakeholders. Hence moving forward, a more diverse group of people has to be engaged in what and how of future touchless technology, given access to this technology and growing understanding of its use in everyday scenarios. In our thematic analysis of expert-based prospects we are making a first step of applying an RI perspective on how touchless systems may evolve and be embedded in everyday life in the future. We encourage everyone to consider RI principles such as anticipation, reflexivity, inclusivity, and responsiveness when innovating especially in contexts of social interactions, which have wide-ranged individual, interpersonal, and implications on society.

To synthesize our lessons from this first prospective expert-based exploration, we propose below a set of guidelines to inform future developments of responsive touchless systems, bridging technical challenges, individuality with responsibilities for design.

Becoming aware of future touchless experiences in todays' technical problem-solving challenges: Touchless systems involve a wide range of technical challenges. This was reflected on the experts' strong interest for solving aspects like latency and reliability. Since this type of stimulation is relatively new and quite different from typical contact-based systems (e.g., vibrotactile feedback), there is a lot to explore and improve. This could often lead to a tunnel-vision focused on problem-solving rather than on the desired experience we aim to achieve. We encourage efforts towards becoming more aware about the "desired experiences" and its consequences in society during the process of addressing the technical challenges touchless systems naturally face.

For example, one latent challenge of touchless systems is that ultrasound-based mid-air haptics is constrained to a fixed device. This limitation has motivated novel solutions around wearable

devices that provide ultrasound feedback to the users' face (e.g., mouth [93]). While this work is highly innovative and addressees various technical challenges (e.g., ultrasound modulation frequency, pressure level, etc.), the practical solutions it provides can come at expenses of user's safety since the effects of ultrasound exposure are still not fully understood [49].

In another example, experts envision different applications around virtual dating, virtual kissing, and virtual handshakes (as demonstrated during our workshops). However, before proceeding with the technical challenges that can involve such applications (e.g., latency, intensity, reliability of the stimulation), we would need to first understand the regulations that might involve "touching at a distance" such as digital intimacies and ethics of consent [62]. In that way, one might avoid introducing potential and unwanted risks (e.g., digital sexual harassment).

Preserving individuality, emotional expressiveness, in the effort of generalizable design: Future touchless applications should consider individuality of people when it comes to applications that aim to elicit, modulate or augment emotional effects. Since touchless interaction is contactless and does not require any physical attachments or actuators, it is often referred to as "digital touch" [55] or "virtual touch" [82]. Moreover, recent work has suggested that emotions can be conveyed through touchless interactions (e.g., mid-air haptics [74]). This can be seen as "digitalizing emotions". We believe this is the motivation of experts for proposing ideas around reduction of complex psychosocial experiences to digital touch sensations. However, we encourage that future developments consider that, emotions are complex experiences and while the positivism of conveying complex psychological experiences digitally is latent among the community, we need to consider not only technical or perceptual aspects but also the complexity of humans and their social and cultural influences.

Thinking about long-term desired and undesired consequences responsibly early on: Thinking of positive consequences is not the only requirement when designing human-computer interfaces. There is an increasing effort to account for possible risks, ethical and moral implications. We should become more mindful and reflective about the question 'what if something goes wrong?' Obviously, there are many efforts already and mechanisms researcher and practitioners go through (e.g., ethics approvals, risk assessment) to prevent any harm to people. However, what we like to stress here is the long-term perspective, that goes beyond one single study, project, or even a single application and technology. Experts during our workshops envisioned mainly a positive future of touchless social applications. However, the critical analysis of those futures demonstrated that multiple unintended consequences, possibly negative ones, are possible. We might identify and discuss some areas in which side effects of using touchless systems. For example, mid-air interactions often cause fatigue [71] and we see increasing safety implications for using ultrasound-based stimulation [9, 29, 49]. We encourage researchers that consider what could go wrong. Thinking negative can help us anticipate potential risks.

Touchless technology is developing and changing constantly and rapidly, as we describe in the evolution of ultrasounds-based mid-air haptics. In the last few years, we saw novel applications ranging from movies with haptic feedback [1] to food levitation [103]. We

call to innovators as we proceed working with this emerging technology, to remain open, adaptable, and flexible to design technology that complies with ethical and socially responsible considerations.

Thinking about the user more diversely: We, as innovators, often develop touchless applications motivated by the novelty (what is new? what have not been done yet? What technical challenges others faced that have remained unsolved?), but we fewer times think of whether the applications we are introducing can be used by everyone (i.e., inclusive applications). For example, while experts during the workshop focused on ideas directed to disable people, they also envisioned scenarios involving technology that seamed directed to wealthier users. For example, systems related to gaming, leisure and entertainment that probably would require expensive equipment or financial capabilities (e.g., remote shared video games, touchless stimulation that encourages you to buy products), and therefore the proposed ideas seem narrowed to a reduced audience. Furthermore, typical system evaluations used in HCI that are directed to "the user", are focused on usability and often motivated around the technical challenges (is this interaction fast enough? Is it frustrating? Is it enjoyable?). We encourage touchless systems innovators to think about "the user" more diversely and consider further areas such as gender, race, experiences, wealth, etc.

5.1 Limitations and future work

While experts were also asked to propose solutions and raise critics of the different ideas, they were largely dreaming about the innovations without actual implementation required. This could explain the hype identified on our analysis. However, we believe that our approach is still a useful starting point that brings a unique perspective from experts actually working on touchless systems in order to inspire practitioners to envision and consider the prospective ethical considerations highlighted in our paper.

Experts were scientists and engineers with no broad knowledge on social science and RI. This can reflect the weigh they put into innovation and technical aspects. However, it is impossible to have experience in all the different perspectives that designing responsible technology requires. Yet, future work will include inviting a broader community with more diverse background such as arts, humanities, and philosophy that can bring a social science perspective to the data collected and thus having a better and more multidisciplinary understanding about potential application and ethical implications.

We are also aware that the workshop participation involved a limited representation of women (as well as non-binary people), being men most of the participants. We believe that this is reflective of the inevitable wider problems of equity and inclusivity in science and innovation. That is, the cross-national research project from which we recruited participants consists mainly of male scientists. Indeed, while reviewing the literature in the field of touchless systems, we sadly noticed that people with expertise in ultrasound-based haptics working both in academia and industry are predominantly male. Therefore, further efforts for recruiting gender-balanced experts participants remain for future work. However, we see our paper itself as a way to reflect on this aspect and give a step towards changing this reality by considering RI perspectives such as

those described in the engagement and inclusivity section of the RI framework.

The responsible framework proposed in this paper is flexible. Our approach aimed to identify some aspects of responsibility, holding open the possibility that there are other important dimensions to touchless responsibility that may become relevant at a later date.

In our workshop we used quantitative scales only for desirability and feasibility. Future work should explore other aspects related to ethics (e.g., security, safety, etc.) in a more quantifiable manner.

6 CONCLUSION

While designing and implementing touchless systems is crucial for the development of the technology, we also need to prospectively analyze the impact technology can have on people so that the designed solutions account and comply to ethical requirements and offer benefits to society. In this paper, we presented how experts working on designing, developing, and evaluating touchless technology, imagine the next generation of touchless systems in social interaction scenarios. We systematically analyzed the emerged 48 ideas, both with regards to relevant features and a RI framework. We conclude by highlighting key considerations to responsibly design future touchless systems that will inevitably enter our everyday life, from how we control interfaces (e.g., in cars, shops, hospitals) and interact with each other (e.g., sharing a kiss over distance). We have now the opportunity to already anticipate and reflect upon desirable futures and avoid undesirable risks and consequences.

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