Information-First Design for Usable and Acceptable Social Robots: Lessons from Dentistry

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Abstract

Social robots are increasingly proposed as affective support tools in healthcare, yet adoption can be limited by poor contextual fit, unclear clinical value, and unresolved concerns around privacy, trust, and security. Dentistry provides a uniquely demanding tested for human–robot interaction: patients are conscious, physically constrained, often anxious, exposed to aversive sensory stimuli, and required to make real-time consent decisions under stress. The dentist has to manage a stressful environment with high speed and precise instruments and cannot afford to be distracted.

Drawing on ecological video analysis of real dental encounters and our recent work on social robots, privacy, and cybersecurity in dentistry, we argue that designing useful and acceptable dental social robots requires a shift from generic affect detection to context-sensitive, phase-aware, and privacy-minimal information collection. This paper reframes social robot design as a question of what information is necessary, when, and under which ethical constraints in high-intensity environments. We outline a preliminary information management framework for dental robotics and show how insights from dentistry generalise to other consumer and healthcare settings involving stress, constrained interaction, and high trust requirements. We argue that dentistry serves as a productive testbed for rethinking information collection in social robots more broadly, and we invite discussion on how these insights might inform future empirical and design work across healthcare and consumer robotics.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Computing methodologies** → *Robotics*; • **Security and privacy** → *Human and societal aspects of security and privacy*.

Keywords

social robots, human–robot interaction, dentistry, healthcare robotics, privacy, trust, cybersecurity

1 Introduction

Human–robot interaction research has demonstrated the potential of social robots to support users emotionally, improve engagement, and reduce anxiety [5, 12]. However, real-world adoption, particularly in healthcare, has been slow [3]. Many robots fail not because they lack social behaviors, but because they collect miss contextual cues, intervene at the wrong moment, or violate implicit expectations around privacy, autonomy, and trust [12].

Dentistry represents an extreme but common healthcare environment: millions of people experience dental care annually, and dental anxiety remains one of the most prevalent treatment barriers [4, 14]. Unlike many clinical settings, dental patients are conscious, often unable to speak, physically reclined, and exposed to intense sensory stimuli (sound, vibration, proximity). This makes dentistry an ideal setting to interrogate what "useful and acceptable" social robots must actually perceive and do. Dentistry can therefore be understood not merely as an application domain for social robots, but as a conceptual laboratory in which tensions between affect, workflow, trust, and data governance become unusually visible.

This paper asks a simple but underexplored question: *What information must a social robot collect in order to be helpful, rather than disruptive, in dentistry, and how should that information be constrained to remain acceptable to users?*

Our analysis is informed by prior empirical observations of dental interactions for anxiety management as well as existing work in HRI, privacy, and cybersecurity [6, 11–13]. Its primary contribution is conceptual: to surface design assumptions, articulate emerging categories of information needs, and outline a research agenda for future work.

2 Dentistry as a Distinct HRI Environment

From the perspective of human–robot interaction, dental clinics impose a set of non-negotiable constraints that fundamentally shape how social robots can perceive, interpret, and act:

- **Constrained communication:** Patients often cannot speak, limiting verbal interaction and increasing reliance on non-verbal cues.
- **High affective load:** Anxiety, fear, and pain anticipation are common and fluctuate rapidly during procedures.
- **Tight spatial choreography:** Dentists, assistants, tools, and the patient occupy a narrow shared workspace with strict infection-control requirements.
- **Real-time consent under stress:** Decisions about treatment continuation, escalation, or stopping occur during heightened vulnerability.
- **Strong privacy expectations:** Dental encounters involve sensitive health data, intimate proximity, and implicit trust.

These conditions mean that a dental social robot cannot function as a generic conversational agent. Instead, it must be phase-aware, minimally intrusive, and deeply respectful of clinical workflow and patient autonomy. These conditions represent a demanding configuration of interactional, ethical, and technical constraints. Dentistry can therefore be understood as a *maximal-demand* environment for social robotics: if a robot can operate safely, acceptably, and meaningfully under such conditions, it is likely to function under less restrictive circumstances elsewhere.

3 Design Elements of Information

Rather than treating data collection as a technical implementation detail, we argue that it should be understood as a central design problem in social robotics. We propose a conceptual framework around data management guided by user acceptability that centers around the following elements: (1) interaction signals (2) procedural phase awareness (3) environmental and workflow constraints (4) security and privacy.

3.1 Interaction signals

Ecological analysis of dental encounters shows that anxiety rarely appears as a single detectable signal [9, 15]. Instead, it emerges as patterns of change: shifts in posture, breath, gaze, micro-movements, hesitations at consent points, or sudden stillness following specific triggers (e.g., drill onset). Moreover, anxiety emerges through a dynamic interaction between the dentist, patient, and social robot, in which subtle cues and actions from each party can amplify or alleviate emotional tension.

Rather than labeling patients as "anxious," a useful robot needs access to moment-to-moment indicators of interactional strain. Such cues include sudden muscle tension or withdrawal, changes in breathing rhythm, rpeated clarification or hesitation and non-verbal stop-signals when speech is impossible. Importantly, these signals only make sense when interpreted in context.

3.2 Procedural phase awareness

Dental care unfolds in distinct phases (arrival, settling, explanation, injection, active treatment, interruption, debrief). The same robot behavior may be helpful in one phase and unacceptable in another.

A socially acceptable robot must therefore know when the patient can meaningfully attend, when the clinician's cognitive load is highest, when interruption is unsafe or unwelcome, and when reassurance or grounding is most valuable. This requires temporal alignment of sensing with clinical workflow.

3.3 Environmental and workflow constraints

Information about spatial layout, line-of-sight, sound peaks, and staff movement is essential—not to optimize robot intelligence, but to prevent harm and disruption. A robot that blocks access, distracts staff, or interferes with sterile routines will be rejected regardless of its social capabilities.

3.4 Security and privacy

Social robots in dentistry are simultaneously social actors, clinical tools, and data-collecting systems. Designing robots that are acceptable in this context, therefore, requires shifting the focus from merely securing robots to constraining what information they are allowed to collect in the first place.

Cyber risks can be assessed using established frameworks such as ISO/IEC 27005 [1] and the NIST Cybersecurity Framework (CSF) [2]. Although no frameworks are specialised for social robots, generic cybersecurity models, including Mitre ATT/CK [16], Cyber Kill Chain [10], and the Diamond Model [7] can be applied to develop threat-informed defences across both physical and cyber dimensions of robotic systems.

Privacy by Design [8] provides a foundational approach for embedding privacy into system architecture from the outset. Prior work indicates that user acceptance is shaped by: (1) transparency about what is sensed and why, (2) tiered and revisable consent, (3) minimal data capture aligned with immediate purpose, and (4) strong security without burdensome authentication. User acceptability, therefore, depends on transparent and constrained data practices.

4 Implications to Broader Consumer Robotics

Although dentistry is a specific domain, its constraints mirror many other healthcare and consumer contexts, where heightened affect, constrained interaction, and strong trust expectations. Dentistry thus serves as a stress-test environment for social robot design principles that generalise well beyond oral healthcare. Our analysis shifts the focus from social expressiveness to selective, context-aware information use. We recognise that, in dentistry and many other domains, social robots operate simultaneously as social actors, clinical tools, and data-collecting systems. This creates inherent tensions between relational continuity and requirements for data minimisation, security, and legal accountability [12]. We argue that these tensions constitute a fundamental design consideration rather than a technical problem, and we invite further discussion on how such competing demands should be balanced in future social robot design.

5 Conclusion

Designing useful and acceptable social robots for dentistry requires careful attention to information ecology, not just interaction design. By identifying the minimum necessary information for affective support in a high-intensity clinical environment, dentistry offers a powerful lens for advancing socially responsible, trustworthy consumer robotics. As a work in progress, this paper is intended to provoke discussion rather than to close debate, and to invite interdisciplinary perspectives on how social robots should be designed for environments where emotional vulnerability, clinical precision, and data sensitivity intersect.

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