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ARTIFICIAL INTELLIGENCE DRIVEN FACIAL TRACKING AND PRIVACY IN METAVERSE PSYCHIATRY: TECHNICAL FOUNDATIONS AND CLINICAL POTENTIAL OF THE META QUEST PRO

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ABSTRACT

The metaverse is rapidly transforming healthcare delivery, especially into psychiatric evaluation and treatment. Among head-mounted displays (HMDs), the Meta Quest Pro distinguishes itself with its built-in artificial intelligence (AI) accelerators and integrated machine learning models that enable real-time facial tracking. These innovations address key metaverse-based mental health care challenges by enhancing emotional realism, patient engagement, and clinical utility. This article discusses the technological foundations required for emotionally responsive avatars and on-device inference, which are critical for preserving privacy in sensitive clinical environments. By evaluating Meta Quest Pro's capabilities, this study positions it as a leading platform in the emerging field of digital psychiatry. This article synthesizes the author's earlier pilot work and publicly available technical documentation; it does not report new empirical data.

1. Introduction

The metaverse, a persistent and immersive digital environment, has emerged as a promising space for remote mental health care [1]. This is particularly true considering the increasing demand for easily accessible psychiatric services [2]. The key to its clinical usefulness is how realistic and emotionally expressive interactions are when using avatars. Historically, virtual clinical environments have struggled to mirror non-verbal patient cues authentically, such as facial expressions, which are essential for psychiatric evaluation. Recent reviews continue to position the metaverse as a viable infrastructure for delivering immersive mental-health services [18], [19].

Recent advances in HMDs, particularly the Meta Quest Pro, have begun to overcome this barrier by integrating on-device AI accelerators and calibration-free machine learning models for real-time facial tracking. It processes raw sensor data captured from five inward-facing infrared (IR) cameras and then employs the Facial Action Coding System (FACS) to animate avatars with linear blend shapes for more naturalistic appearance expressions.

Unlike VR headsets that rely on external processing[3] the Quest Pro performs these computations on-device, leveraging AI-optimized hardware for low-latency, privacy-preserving inference.

In virtual psychiatric sessions, dynamic avatars play a critical role in maintaining the therapeutic alliance between patients and practitioners [4]. The AI's capability to capture and replicate non-verbal cues ensures a deeper level of emotional engagement and authenticity. Recent evidence from fully virtual telepsychiatry practices confirms that a strong therapeutic alliance can be established remotely and remains a significant predictor of clinical improvement [15]. Avatar design — including customization and embodiment — has also been shown to influence therapeutic outcomes in virtual mental-health interventions [16].

Traditional CPUs and GPUs, while competent, are not optimized for the specialized computational tasks required for neural networks [5]. In contrast, AI chips are designed to rapidly process deep learning algorithms with high efficiency and low latency, making them ideal for applications involving continuous sensor data interpretation and avatar animation. In the case of the Meta Quest Pro, these chips are responsible for converting complex facial muscle signals into actionable avatar expressions at speeds fast enough to keep up with live conversation.

In the larger picture of AI chip development, the Meta Quest Pro represents a transition from general-purpose processors to using specialized AI hardware designed for specific tasks like facial recognition, natural language processing, and gesture tracking. As Moore's Law slows and transistor miniaturization faces physical limits, the evolution of dedicated AI processors will be central to sustaining performance in immersive and intelligent systems [5].

This article builds on our previously published pilot study [6], which demonstrated the feasibility of using the Meta Quest Pro's AI-powered facial tracking for psychiatric assessment in virtual environments. This study employed a within-subjects design, where each participant used the Meta Quest Proand experienced two sessions: one in a metaverse environment and the other in a traditional in-person clinic. The results show promising similarities in patient satisfaction, diagnosis consistency, and therapeutic relationships between the two settings. This article extends that work by providing a comprehensive technical and clinical analysis of Meta Quest Pro's capabilities, addressing broader implications for AI-driven mental health applications and privacy-preserving digital care.

This paper is structured as follows: The first section explores the foundational elements of the Meta Quest Pro, including embedded artificial intelligence, real-time facial tracking, on-device AI processing, and privacy preservation. Subsequent sections present an overview of the technical infrastructure that enables these capabilities. Section 2 includes a comparative analysis between the Meta Quest Pro and other HMDs. Section 4 concludes, and Section 5 outlines future work.

2. AI-Driven Capabilities in Immersive Mental Health Platforms

This section discusses the integration of embedded AI and real-time facial tracking in the Meta Quest Pro and how this enhances the technical realism of avatar communication and addresses clinical challenges in virtual psychiatric assessment and therapy.

2.1 Embedded AI and Real-Time Facial Tracking

A defining advancement of the Meta Quest Pro is its capacity to perform real-time facial tracking entirely on-device, eliminating the need for external calibration or dependence on cloud-based processing. This feature is powered by pre-trained machine learning models executed on specialized AI accelerators within the Qualcomm Snapdragon XR2+ Gen 1 chip, designed for high-throughput, low-latency inference [7]. The headset's five inward-facing infrared cameras continuously capture nuanced facial and ocular movements, providing a rich stream of biometric data. The headset operates as a standalone wireless device with no external sensors or tethered PC.

The facial tracking pipeline leverages the Facial Action Coding System (FACS), a validated framework for quantifying human facial muscle movements [8][9]. The on-device AI models interpret raw sensor input and convert it into a set of abstracted parameters—known as blend shapes—that represent the intensity of specific facial actions on a normalized scale (zero to one).
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These blend shapes are then mapped in real time to the user's avatar, enabling a spectrum of naturalistic expressions such as brow furrowing, eye blinking, lip movement, and subtle micro-expressions. Recent comparative work has further characterised the accuracy and inter-individual variability of the Meta Quest Pro's built-in eye- and face-tracking pipeline [14].Figure 1(a) shows the Meta Quest Pro with its five inward-facing IR cameras; Figure 1(b) illustrates avatar lip movement and micro-expression

(a) (b)

Figure 1: (a) Meta Quest Pro (b) Avatar lip movement.

This technological innovation has significant implications for psychiatric practice in virtual environments. In conventional telepsychiatry or virtual consultations, the absence of expressive non-verbal cues has been shown to decrease the therapeutic alliance and limit the clinician's ability to assess affective states [6]. The Meta Quest Pro's embedded AI-driven facial tracking addresses this gap by allowing clinicians to observe and respond to subtle facial indicators of anxiety, stress, or emotional shifts—cues that are often critical for diagnosis, rapport-building, and therapeutic engagement. Furthermore, the immediacy and fidelity of avatar expressions foster a sense of presence and emotional authenticity that is essential for patient engagement in psychiatric care. On-device AI processing significantly reduces latency, ensuring that facial expressions and micro-expressions are captured, interpreted, and rendered in real time. This quick feedback is essential for maintaining smooth conversations in therapy and showing small emotional signals that are crucial for understanding and building trust in mental health assessments.

2.2 On-Device AI Processing and Privacy

The design of Meta Quest Pro offers several critical advantages for psychiatric applications in the metaverse. Local processing of sensitive biometric data, such as facial movements, gaze, and affective signals, addresses major privacy and security concerns associated with [10] in the United States and the General Data Protection Regulation (GDPR) in the European Union [11]. Both frameworks emphasize the minimization of data exposure and advocate privacy-by-design principles in digital health technologies. Recent legal-technical analyses argue that biometric and inferred data collected by facial- and eye-tracking sensors in the metaverse raise distinct privacy questions that current frameworks only partially address [17].Beyond local processing and alignment with health-data privacy standards, the device provides user control and transparency. Users have granular control over natural facial expressions and eye-tracking features. These options can be enabled or disabled at the device or app level, and users can pause or revoke access at any time through the headset's settings. This empowers individuals to manage their privacy preferences and restrict data sharing to only trusted applications. In addition, the privacy-by-design approach supports secure and scalable deployment in clinical environments. By ensuring that sensitive data is processed and deleted locally, the Quest Pro enables broader adoption in psychiatric care, where patient trust and confidentiality are paramount.

Many competing HMDs rely on external servers or PC-based processing for advanced facial tracking [12]. Table 1compares the Meta Quest Pro with the HTC Vive Focus 3 and Valve Index [3][12]. It focuses on features most relevant to clinical and psychiatric use, such as facial tracking, privacy, AI processing, and ease of deployment. It describes that in Meta Quest Pro, all facial and eye data are processed locally. In addition, it is the only device in this comparison with built-in advanced facial and eye tracking suitable for psychiatric and affective-computing applications.

Table 1 Comparison of Meta Quest Pro and Other HMDs for Psychiatric Applications

Feature/Spec	*Meta Quest Pro*	*HTC Vive Focus 3*	*Valve Index*
Facial Tracking	Advanced (5 IR cameras, FACS-based, on-device ML)	No dedicated facial tracking	No dedicated facial tracking
Eye Tracking	Yes, built-in	No (optional add-on in business edition)	No
On-Device AI Processing	Yes (Qualcomm Snapdragon XR2+ Gen 1 AI SoC)	Limited (Qualcomm XR2, less AI focus)	No (PC-based processing)
Privacy Approach	All facial data processed locally; no raw images leave device; aligns with HIPAA/GDPR	Some on-device processing; less explicit privacy controls	Data processed on PC; privacy depends on PC security
Standalone Operation	Yes	Yes	No (PC-tethered only)
Resolution (per eye)	1800 x 1920	2448 x 2448	1440 x 1600
Field of View	~106°	~120°	~130°
Refresh Rate	90Hz (up to 120Hz experimental)	90Hz (up to 120Hz)	80/90/120/144Hz
Hand Tracking	Yes (built-in)	Yes	No (controller-based only)
Ease of Deployment	High (wireless, no external sensors needed)	High (wireless, no external sensors)	Moderate (requires external base stations and PC)
Clinical Suitability	Excellent (privacy, facial/eye tracking, ease of use)	Good (privacy less explicit, no facial tracking)	Limited (no facial/eye tracking, PC required)
Intended Use	Mixed reality, enterprise, clinical, research	Enterprise, business, VR collaboration	Gaming, research

In addition, on-device inferences support robust offline functionality. This is particularly important for extending psychiatric services to regions with limited or unreliable internet connections, where cloud-dependent solutions would be impractical or inaccessible. By allowing all main AI features—like real-time facial tracking and avatar animation—to work without needing an internet connection, the Meta Quest Pro makes it easier to access and expand metaverse-based psychiatric care.

The way the Meta Quest Pro is designed to protect privacy is very important in mental health settings, where keeping biometric and behavioral data safe is crucial. Patients and clinicians can engage in virtual consultations with greater confidence that their personal information remains protected, fostering trust and facilitating broader adoption of digital mental health interventions.

3. Technical Foundations

This section offers an in-depth look at the technical infrastructure that underpins the Meta Quest Pro's capabilities for real-time, emotionally expressive, and clinically relevant avatar interactions. It explains the hardware and software processes, such as using advanced sensors, built-in AI, and special SDKs, to illustrate how these technologies can transform digital psychiatry and mental health support in the metaverse.

3.1 AI Hardware and Facial Tracking Workflow

Meta Quest Pro represents a significant advancement in avatar technology, enabling more emotionally expressive and realistic interactions within the metaverse. Its facial tracking system integrates sophisticated sensor hardware, embedded machine learning, and real-time animation software, all designed to ensure low-latency performance while maintaining user privacy. Figure 2 presents the AI hardware and facial tracking workflow. Then, a detailed description of the workflow is discussed. This workflow not only advances the technical realism of avatar-mediated communication but also addresses critical privacy and security concerns. By processing all biometric data locally, the Meta Quest Pro minimizes the risk of data breaches and aligns with major healthcare regulations such as HIPAA and GDPR. This privacy-preserving approach is particularly important for psychiatric applications, where the sensitivity of facial and affective data demands stringent safeguards.

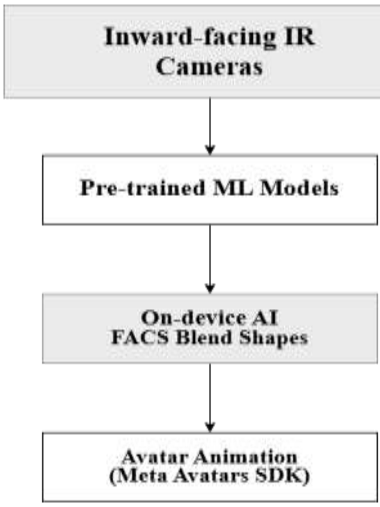

Figure 2: Meta Quest Pro Facial Tracking Workflow

1. Five inward-facing infrared (IR) cameras: At the heart of Meta Quest Pro's sensing system are five inward-facing IR cameras, strategically positioned to capture high-resolution data on both facial expressions and eye movements [13]. Three cameras focus on the upper face and eyes, while two are dedicated to the lower face, ensuring comprehensive coverage of facial muscle activity. This configuration enables the device to continuously monitor subtle changes in facial musculature and ocular behavior—data essential for accurate emotion recognition and nuanced avatar animation.

2. Pre-trained Machine Learning models: The raw data collected by the IR cameras is processed locally using pre-trained machine learning models embedded within the headset. These models are specifically trained to interpret complex patterns of facial muscle movement and translate them into standardized parameters based on the Facial Action Coding System. Each facial action unit is mapped to a corresponding "blend shape," a normalized value (ranging from 0 to 1) representing the intensity of a specific facial movement (e.g., eyebrow raise, smile, frown). This approach ensures that the avatar's expressions are not only lifelike but also semantically meaningful, supporting clinical use cases that depend on subtle affective cues.

3. On-device AI accelerators: A key innovation of the Meta Quest Pro is its reliance on on-device AI accelerators, specifically the Qualcomm Snapdragon XR2+ Gen 1 system-on-chip (SoC). Unlike traditional HMDs that depend on external servers or general-purpose CPUs/GPUs, the Quest Pro's dedicated AI processing units perform neural network inference tasks with high efficiency and minimal power consumption. This architecture enables real-time, low-latency processing of facial and eye-tracking data, ensuring that avatar expressions are updated instantaneously and without perceptible delay. Such responsiveness is critical for maintaining naturalistic social interactions and therapeutic rapport in psychiatric consultations [6].

4. Meta Avatars SDK: The final stage of the workflow involves the Meta Avatars software development kit (SDK). This SDK provides the necessary tools and APIs to map blend-shape data onto the avatar's facial rig in Unity or Unreal Engine. The SDK translates the FACS-based blend shapes into smooth, continuous facial animations, synchronizing them with eye gaze and head movements to create a cohesive and emotionally expressive virtual presence. This seamless integration of hardware and software is fundamental to Quest Pro's ability to deliver immersive, emotionally intelligent experiences in the metaverse.

4. Conclusion

Meta Quest Pro's AI-powered facial tracking exemplifies the practical fusion of machine learning, sensor technology, and edge AI processing. This headset serves as more than a tool—it is a case study in how AI chip innovation enables rich, expressive, and clinically viable experiences in the metaverse. It is a useful step toward making immersive digital healthcare feasible in clinical practice. This article explores the technological foundations necessary for developing emotionally responsive avatars, which are essential for maintaining user privacy in sensitive clinical contexts. It offers a comprehensive analysis of the Meta Quest Pro's technical and clinical

5. Future Work

While the Meta Quest Pro demonstrates significant promises for AI-driven psychiatric care in virtual environments, several avenues remain for future research to fully realize its clinical and technological potential:

- **Integrate Physiological Sensors for Multimodal Emotion Detection:** The next generation of virtual mental health platforms should incorporate additional biosensors—such as heart rate monitors, galvanic skin response, or EEG—to enable multimodal emotion recognition. By combining facial expression analysis with physiological data, we can enhance the sensitivity and specificity of affective state detection, thereby supporting more personalized and adaptive therapeutic interventions.
- **Further Benchmark Privacy, Latency, and User Experience Against Emerging HMDs:** As the landscape of head-mounted displays continues to evolve, it is essential to systematically benchmark the Meta Quest Pro's privacy protections, processing latency, and user experience against both current and next-generation devices. Comparative studies should assess not only technical performance but also user trust, comfort, and clinical usability in sensitive healthcare contexts.

By addressing these areas, future research will help establish robust evidence for the safe, effective, and ethical integration of AI-driven virtual reality technologies in psychiatric practice.

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