EMiRAs-Empathic Mixed Reality Agents

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ABSTRACT

In recent years, there has been a growing body of research at the intersection of Mixed Reality (MR), Empathic Computing (EC), and agent technologies. Despite this trend, a unified theoretical framework to guide such research remains elusive. This paper introduces the concept of Empathic Mixed Reality Agents (EMiRAs), emerging from the convergence of Empathic Agent (EA), Mixed Reality Agent (MiRA), and Empathic Mixed Reality (EMR). We present the Corporeal Presence and Interactive Capacity (CPIC) matrix as a tool for examining EMiRAs-related studies, enabling systematic exploration of agents' embodiment and environmental interaction capabilities. By conducting literature reviews organized within the CPIC matrix, we investigate the current landscape of EMiRAs research. Additionally, we discuss the challenges and opportunities inherent in developing EMiRAs. This work contributes to laying the groundwork for future advancements in the field by providing a comprehensive framework and analysis of EMiRAs-related research endeavors.

CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models**; • **General and reference** → *General literature.*

KEYWORDS

Empathy, Mixed Reality, Agent

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1 INTRODUCTION

In the field of Artificial Intelligence (AI), an agent is defined as "Anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators" [42]. As is shown in Figure 1, perceiving and acting on the environment are two important capabilities of an agent. For example, agricultural robots employ multi-sensor fusion, integrating machine vision, radar, and inertial devices, to perceive the intricate outdoor field environment accurately. These robots leverage actuators such as hydraulic cylinders, and linear and rotary motors to drive end-effectors, enabling diverse tasks like harvesting fruits, spraying, and more [52]. In the social interaction area, creating social agents that can engage users in social interactions has attracted a lot of research attention [8, 30]. As has been addressed by Paiva [32], creating empathy in social agents is challenging but beneficial for enhancing human-agent interaction. Paiva et al. [33] further define an Empathic Agent (EA) as an agent that can show empathy towards the users or, by its design, lead users to show empathy towards it.

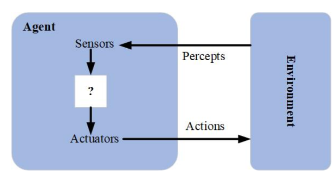

Figure 1: An agent can perceive and act on its environment through sensors and actuators [42].

The empathic agents reviewed by Paiva et al. [33] were embodied in entirely virtual environments like Intelligent Virtual Agents (IVAs) or physical environments like robots. However, as the Mixed Reality (MR) [24] technology evolves, agents can exist simultaneously in both virtual and physical environments. An agent embodied in a Mixed Reality environment is called a Mixed Reality Agent (MiRA) [14], and can interact with both physical and virtual environments. Previous research has shown that a virtual agent's interaction with the physical environment increases copresence, social presence, and engagement [18, 22, 35]. Moreover, from the agent's perspective, the human user is also part of the physical environment. Agents' capabilities of sensing and acting on users are important to create empathic communication between humans and the virtual agent. For example, Boucaud et al. [5] developed a virtual human where users can touch it through haptic feedback on the user's hand and arm.

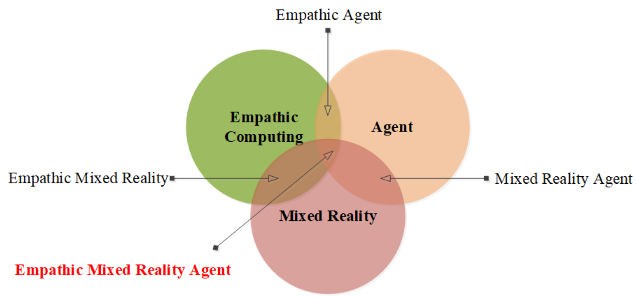

Figure 2: The Empathic Mixed Reality Agents (EMiRA) venn diagram [9].

As addressed by Billinghurst [4], Piumsomboon et al. [36], Empathic Mixed Reality (EMR) is an MR system that creates a deeper understanding and empathy between people. More and more MR systems are integrating multiple sensors to support implicit understanding of users' interaction intentions and even emotional and cognitive states. For example, the Apple Vision Pro[1] provides eye gaze and hand gestures to interact with virtual content. The Galea headset [2] integrates physiological sensors like electromyogram (EMG), electroencephalogram (EEG), electrooculogram (EOG), electrodermal activity (EDA), photoplethysmogram (PPG), which allows the MR system to detect user cognitive states through those physiological sensors. Using these MR systems, MiRA can perceive human states in more detail and even provide an empathic touch toward users through controllers, data gloves, and other haptic devices. Norouzi et al. [27] showed that the intersection of Augmented Reality (AR), IVAs, and the Internet of Things (IoT), created the possibilities for enabling agents to interact with the AR environments through IoT sensors. In short, EMR benefits from multiple sensors, which provides opportunities for creating empathy in MiRAs.

Although much research has been done in both EA and MiRA, less attention has been paid to the EAs that embody MR environments, especially when the MR environment is equipped with rich physiological and IoT sensors. In this paper, we introduce the concept of Empathic Mixed Reality Agents (EMiRAs), delving into the essential capabilities to foster empathy. We provide a tool to categorize the EMiRAs and explore their challenges and opportunities.

2 CONCEPT OF EMPATHIC MIXED REALITY AGENT

As is shown in Figure 2, we define an Empathic Mixed Reality Agent as "An empathic agent embodied in an empathic mixed reality environment", so the intersection of EA [33], MiRA [14] and EMR [36]. We will first connect the EMiRA with an empathy theory model and then discuss the relationship between EMiRA and MiRA, EA and EMR. In exploring the connection between EMiRA and MiRA, we further developed a tool based on the MiRA cube proposed by Holz et al. [14] for assessing the corporeal and interaction capabilities of EMiRAs.

[1]https://www.apple.com/apple-vision-pro/
[2]https://galea.co/home

In general, an EMiRA is an agent that can perceive information from the environment in which it is embodied and act on its surroundings. In line with the agent concept shown in Figure 1, Preston and De Waal [38] proposed the Perception-Action Model (PAM), which describes the ultimate and proximate mechanism of different perspectives of empathy such as emotional, cognitive, and conditioning views. Based on the PAM, Rodrigues et al. [41] proposed a computational empathy model for social agents, which comprised an empathic appraisal and empathic response. In this model, the empathic appraisal happens when an agent perceives a new event that elicits an emotional cue in another agent, whereas the empathic response takes place with an emotion generated by the empathic appraisal. According to the agent concept and PAM theory, the empathic appraisal is based on the perception of the environment, while the empathic response could be built upon actions shown by the agent towards the environment.

An EMiRA is a MiRA that can have both virtual and physical bodies and interact with both environments. Inspired by the concept of MiRA cube proposed by [14], we propose the EMiRA Corporeal Presence and Interactive Capacity (CPIC) Matrix (See Table 1) to classify different levels of EMiRA capabilities. According to [14], the corporeal presence of an MiRA refers to the degree of virtual or physical representation, while the interactive capacity represents an agent's ability to sense and act on the virtual and physical environment.

In our proposed CPIC matrix, we examine different combinations of corporeal presence types and interactions with different environment types. For example, Dragone et al. [11] designed a MiRA by augmenting a virtual character into a physical robot with both virtual and physical body parts. The virtual body part could gaze and point at a physical ball, while the physical body part could move toward the target, grab the ball, and take it back to the user. This demonstrates how an agent with a mixed body could interact with the physical environment, including both human and non-human objects (MP).

As shown in Table 1, we exclude three types of agents from EMiRA's CPIC matrix because they do not belong to MiRA and, therefore, cannot be incorporated into EMiRA. The first type is the agents embodied only in virtual environments and can only interact with virtual environments. For example, some of the Non-Player Characters (NPCs) in computer games can hang around in the virtual game environment but cannot interact with players. The second and third types can be concluded as the agents embodied only in the physical environment and can only interact with the physical environment. For example, industrial robots can pick and place parts on production lines [3], and social robots can communicate with people (From the perspective of agents, human is also part of the physical environment) naturally using verbal and nonverbal cues [7]. Furthermore, it is worth noting that multi-embodiment agents, as discussed in prior work [16], which possess the capability to switch between different environments dynamically, can also be evaluated using our CPIC matrix. This assessment involves examining diverse combinations of corporeal presence and interactive capacities across different embodiment states, which vary depending on the number of embodiment states that such multi-embodiment agents possess.

Compared with the MiRA cube [14], our CPIC matrix further divided the physical environment into non-human objects and humans. We made this division for two reasons. First, from the perspective of an agent, human users are part of the physical environment. Second, based on the concept of EA, we believe studying the interaction between humans and MiRAs is vital to fostering empathy in our proposed EMiRAs.

An EMiRA is a kind of EA that can show empathy towards human users or, by its design, could elicit human empathy towards the agent [33]. To create such an empathic relationship between the human user and the EMiRA, it is important to build the agent's capabilities of sensing and acting on human users with multiple sensors and technologies such as eye tracking, motion and position tracking, and physiological tools [23]. For example, Kevin et al. [17] created a virtual teacher who could recognize students' attention through eye gaze. Similarly, Vrins et al. [49] presented a robot tutor for language learning which could make adaptive responses based on the detected user attention through an online Brain Computer Interface (BCI).

Utilizing multiple sensors and actuators to create a deeper understanding of the human state while interacting with mixed reality systems is one of the key aspects of EMR systems [44]. Moreover, the EMR environment enables the embodied EMiRA to sense and act on the environment [21]. Therefore, the EMR serves as an important basis for the EMiRA.

Since an EMiRA is embodied in the MR environment, it is worth exploring how the agents' virtual-physical interaction capabilities in the CPIC matrix influence user-perceived empathy. Therefore, we will provide a literature review on the agent's capabilities of sensing the environment in section 3 and acting on the environment in section 4.

3 CAPABILITY OF SENSING ENVIRONMENT

One of the important capabilities of EMiRAs is sensing the environment. As shown in Table 1, such sensing capability can be further classified into sensing the virtual environment, sensing the physical environment, and sensing both the virtual and physical environment (MR environment).

A MiRA sensing the virtual environment can be classified into PV or MV in Table 1. For example, Phan et al. [34] explored MR collaboration between human-agent teams where dispersed humans and physically embodied drones could pass through a virtual doorway while avoiding collisions. Han et al. [12] presented the design of physical robots with either physical or virtual arms that could point at virtual objects. Although these examples demonstrate the capability of PV and MV, such research didn't look into building empathy in the MiRA.

MiRAs sensing the physical environment can be further classified into agents embodied in the virtual environment sensing the physical environment, including VPN and VPH, or agents embodied in both virtual and physical environments but sensing the physical environment, including MPN and MPH. For example, Avramova et al. [2] demonstrated a virtual poster presenter that could adjust its virtual body based on the user and physical poster positions (VPN + VPH). Kim et al. [22] found a virtual human in MR aware of the real-world fan (i.e., VPN) improved social presence. Similarly, Pimentel and Vinkers [35] also found when a virtual human in MR showed awareness of physical events like the sound produced by a broom falling onto a metal cabinet (i.e., VPN), it improved co-presence. Unlike those agents with the human body shown above, Norouzi et al. [29] explored the impact of a virtual dog's awareness of humans on users' perceptions and behaviors. They found the dog's awareness of other people (i.e., VPH) positively influences the users' perceived co-presence and animalism of the dog. Moreover, Ali et al. [1] proposed a framework for creating multi-modal interaction IVAs in MR by integrating spatial mapping, virtual character, chatbot, and object recognition. They presented a botanical garden demo where users could talk with a virtual agent on a real plant in the physical environment (i.e., VPN+VPH). For the MPN and MPH, both [25] and [55] presented agents with both virtual and physical bodies that could move around in mixed-reality environments and interact with human users. More examples of such agents capable of sensing the physical environment can be found in [20, 25, 51, 55]. However, these works have yet to explore whether agents sensing the physical environment influence their perceived empathy.

Combining the agents' capability of sensing both virtual and physical environments, we can identify agents perceiving MR environments, including VM, PM, and MM. For example, Ye et al. [54] proposed position-aware virtual agents that could automatically move in real time to navigate users through virtual environments. The virtual agents' position and orientation were determined based on the user's current position and orientation. From the perspective of such virtual agents, they can sense both human and virtual environments and thus belong to VM. Villanueva et al. [48] presented an AR-compatible robot that behaves as a student tutor with access to the physical and virtual worlds. Similarly, Qiu et al. [39] designed a shared AR workspace where a physical robot can not only perceive virtual information in its view but also sense the human collaborator's gaze and pose. These two systems demonstrate the capability of PM agents.

Overall, we review MiRAs capable of sensing the environment in this section. Through the review, we found that not much attention had been paid to exploring empathy creation in MiRAs by considering the capability of sensing the environment, especially sensing human users. We will discuss research opportunities related to this problem in section 5.

4 CAPABILITY OF ACTING ON ENVIRONMENT

Similar to the sensing capability, EMiRAs' acting on environment capability can also be categorized by the Table 1.

MiRAs functioning in virtual environments can be classified into PV and MV. PV involves a physical body interacting with virtual environment objects, while MV involves both virtual and physical bodies engaging more extensively with the virtual environment. For example, the physical robot inside the AR workspace proposed by Qiu et al. [39] could not only sense the physical environment but also proactively manipulate virtual holograms, which demonstrates the capability of PV. However, whether the capability of PV and MV influence the perceived empathy in EMiRA is far more explored.

Table 1: EMiRA's Corporeal Presence and Interactive Capacity (CPIC) matrix (The acronyms listed in this table are formed from the initial letters of the corresponding row and column names. The row names denote the corporeal presence characteristics of the agents, while the column names indicate their interaction capabilities with the respective environment.

	Virtual Environment	Physical Environment		Mixed Reality Environment
		Non-human objects	Human	
Virtual Embodiment	–	VPN	VPH	VM
Physical Embodiment	PV	–	–	PM
Mixed Reality Embodiment	MV	MPN	MPH	MM

Legend: – (This type of agent doesn't belong to EMiRA.), PV (The agent embodies only in the physical environment but interacts more with the virtual environment.), MV (The agent embodies in both virtual and physical environments but interacts more with the virtual environment.), VPN (The agent embodies only in a virtual environment but can interact with non-human objects in the physical environment.), VPH (The agent embodies only in the virtual environment but can interact with human users.), PPH (The agent embodies only in the physical environment and can interact with human users.), MPH (The agent embodies virtual and physical environments but interacts more with human users.) VM (The agent embodies only in the virtual environment but can interact with both virtual and physical environments.), PM (The agent embodies only in the physical environment but can interact with both virtual and physical environments.), MM (The agent embodies both virtual and physical environments and can interact with both environments.)

When creating MiRAs interacting with the physical environment, research typically utilizes IoT sensors for non-human objects, including VPN and MPN, and wearable haptic devices for human users, including VPH and MPH. For example, Kim et al. [19] presented a virtual human embodied in an MR environment that could move around in the real environment to switch off the physical bulb, showing the capability of VPN in the virtual human. They found such capability could improve perceived social presence and human trust in the virtual agent. Similarly, Schmidt et al. [43] introduced a virtual human to play a physical golf ball. Although they didn't find a significant difference between virtual agents with and without the capability to act in the physical environment, participants' responses collected from their study still indicated the benefits of the former. Unlike these two VPN examples, Dragone et al. [11] introduced the MiRA, where a virtual character was augmented on top of the robot. That MiRA is capable of grabbing a physical ball and giving it back to human users shows the capability of MPN and MPH. Although these agents exemplify the capability and benefits of acting on physical non-human objects, how such capability influences the perceived empathy in EMiRAs is still unclear.

When the physical environment is narrowed down to human users, the EMiRAs' capability of acting on users becomes empathic touch which is also an interesting research field. For example, Boucaud et al. [6] explored social touch for an IVA in a virtual environment where users could get haptic feedback from the virtual agent on the hand and arm. They highlighted the importance of exploring credible empathic touch through different patterns of vibrations. They also demonstrated how humans identify the emotions conveyed by the IVAs to humans by combining the virtual agent's facial expression and touch. Similarly, Okumoto et al. [31] presented tactile gloves that allowed users to feel tactile stimuli from virtual characters and use fingers to push or pick them. Their preliminary test results showed positive evaluations of the interaction between the virtual character and users. These examples indicate promising trends in creating empathy between human users and agents through well-designed haptic feedback.

The situation of MiRA acting on MR environment can be exemplified by the Ghosts-in-the-city Game presented by Ricci et al. [40]. In this game scenario, human players can perceive Ghosts through AR glasses while the Ghosts can move freely within the physical city environment. Such agents exist in both virtual and physical environments. The Ghosts' goal is to chase after the human players when they perceive the humans around them and grab a human player's body by triggering trembling in the smartphone in the player's hands, which serves as a magic wand. This indicates such agents can sense and act on human users. Moreover, the Ghosts in this game can also perceive the physical environments' humidity, light, and temperature. Powerful human players can use the magic wand to create temporary virtual holes in the ground to absorb the Ghosts, which shows such Ghosts can also be influenced by the virtual environments. Although this example demonstrates the MiRA's capability of sensing and acting on the MR environment, it does not address the empathy in such agents.

In short, we provide examples of MiRAs capable of acting on the environment organized by the Table 1. We found that providing the agents with the capability to show empathic touch towards human users is promising in improving perceived empathy in such agents. However, whether the capability to act on non-human objects in physical environments or MR environment influences the empathy between humans and the agent is still unclear. We will discuss this in the following section 5.

5 OPPORTUNITIES AND CHALLENGES IN EMIRAS

In this section, we discuss opportunities and challenges in EMiRAs based on section 3 and section 4, and provide reflections on creating empathy with EMiRAs. According to the definition of EA [33] and literature reviews in section 3 and section 4, we believe that enabling the agents' capabilities of sensing and acting on human users is key to improving the perceived empathy with such agents.

Research opportunity 1: Enabling EMiRAs to more deeply understand humans. To enable agents to more deeply understand human users, cameras, eye tracking, motion tracking systems, and similar technologies can be used to effectively monitor body movement and facial expressions. In addition, physiological sensors such as EEG, EDA, and PPG can capture user physiological states. Although a lot of work has been done to detect human cognitive and emotional states from multi-sensory data [15, 56], it could still be challenging to allow the agents to accurately capture users' real-time cognitive and emotional states. For example, Prendinger and Ishizuka [37] presented an empathic virtual interviewer detecting user affective states using GSR and heart rate and providing empathic responses towards users based on the detected user affective states during the simulated interview. However, their exploratory study results did not find a positive effect from using the empathic agent. They provide reflections on issues in real-time assessment of physiological data. Given the challenge of accurately detecting human real-time emotional states, it is valuable to consider whether an EMiRA requires only awareness of users' physiological states or necessitates an understanding of their cognitive and emotional states inferred from physiological signals. For instance, agents could use knowledge of users' heart rate changes to adapt their behaviors without inferring users' emotional states based on heart rate.

Research opportunity 2: Understanding the impact of EMiRAs' multimodal communication cues on human perception. An agents' multimodal verbal and nonverbal communication cues [50] is the information expressed by the agents that can be perceived by human users. It is important to understand how such cues could impact users' perceptions and behaviors before making adaptive empathic responses. For example, Chang et al. [10] used EEG to measure the impact of virtual agent behaviors on user cognitive load and attention. They found that the agent's embodiment could influence the users' perception of sudden behaviors expressed by the agent. Szafir and Mutlu [45] created an adaptive agent that could monitor users' attention based on EEG and make adaptive behaviors to recapture the users' attention. Such closed-loop adaptation in MiRAs based on sensing and acting on human users is more complicated and under-explored. Moreover, as has been highlighted in [46, 47], social touch can be one of the nonverbal cues in social agents promising to create empathy. However, little attention has been paid to creating empathic touches in MiRAs and understanding their impact on human perception and behaviors.

Research opportunity 3: Exploring factors that foster empathy in EMiRAs. In addition to prioritizing interactions with human users, exploring how interactions with the non-human environment could foster empathy [26]. Previous research has shown an agent showing awareness of physical environment events [22] and being able to influence the environment [19] could improve perceived social presence and engagement. However, how such capabilities could be used to create empathy in MiRAs is still unclear. Moreover, there is little research demonstrating a MiRA with physical and virtual embodiment interacting with both physical and virtual environments in section 3 and section 4. How such agents' characteristics benefit their perceived empathy is still under-explored.

Challenge 1: Ethical concerns. While enhancing EMiRAs with the ability to sense and respond to the environment could foster empathy, it also raises ethical considerations. For instance, determining which physiological data should be disclosed to EMiRAs raises concerns about privacy infringement. As discussed by Kim et al. [19], embodied virtual agents in MR, capable of interacting with the physical environment, also pose potential privacy risks. Furthermore, when agents utilize actuators or haptic feedback to directly touch users, there is a risk of causing harm. In addition, agents influencing the physical environment may pose health risks, such as opening an oven and causing a fire.

Challenge 2: Evaluating perceived empathy. Another challenge in EMiRAs is the lack of effective methods to evaluate the perceived empathy in agents. As addressed by Yalçın [53], despite the availability of well-established methods from psychology, psychiatry, and neuroscience to measure empathy in humans, the translation to evaluate empathy in artificial agents is not straightforward. There is a need for more research on ways to measure empathy with virtual characters.

In summary, although creating empathy for EMiRAs is challenging, potential applications and benefits of such social agents [13, 26, 28] are promising for human-agent interaction. As the challenges above show, there is still significant research that can be conducted in this space.

6 CONCLUSION AND FUTURE WORKS

In this paper, we introduce the concept of EMiRA, which arises from the convergence of EA, MiRA, and EMR. We introduce the CPIC matrix as a framework for organizing EMiRA-related research. Through literature reviews categorized using the CPIC matrix, we explore agents' abilities to sense and interact with the environment. Drawing from this review, we also address the challenges and opportunities presented by EMiRAs.

In the future, we plan to investigate the impact of EMiRAs' awareness of user physiological states like Skin Conductance Level (SCL) on perceived empathy. A subsequent user study involving two factors would be crafted to investigate how agents' awareness of both user physiological states and external events, such as phone ringing or door opening, interact during interactions. These planned investigations represent incremental progress in addressing the challenges of EMiRAs, underscoring the need for collaborative endeavors to explore this field further.

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