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HybridMingler: Towards Mixed-Reality Support for Mingling at Hybrid Conferences

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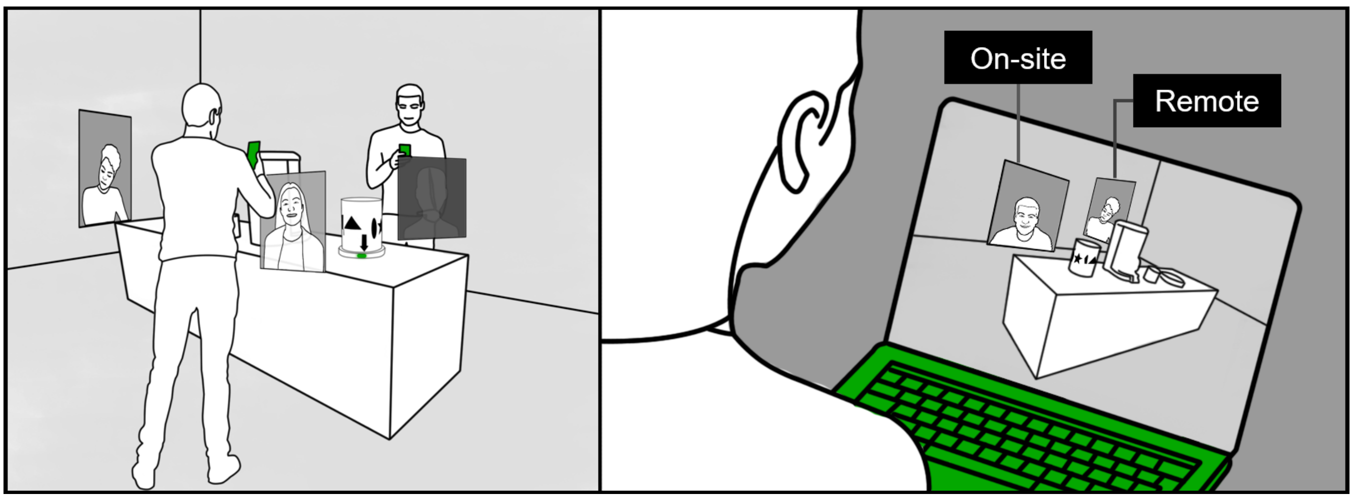

Figure 1: HybridMingler concept illustrations: On-site attendees while mingling with remote attendees through a mobile MR interface after scanning the physical meet-up hub (left) and remote attendee while mingling using a 3D interface, enabled for VR, where she can see on-site and remote attendees spatially anchored in a virtual copy of the physical mingling space (right).

ABSTRACT

Mingling, the activity of ad-hoc, private, opportunistic conversations ahead of, during, or after breaks, is an important socializing activity for attendees at scheduled events, such as in-person conferences. The Covid-19 pandemic had a dramatic impact on the way conferences are organized, so that most of them now take place in a hybrid mode where people can either attend on-site or remotely. While on-site attendees can resume in-person mingling, hybrid modes make it challenging for remote attendees to mingle with on-site peers. In addressing this problem, we propose a collaborative mixed-reality (MR) concept, including a prototype, called HybridMingler. This is a distributed MR system supporting ambient awareness and allowing both on-site and remote conference attendees to virtually mingle. HybridMingler aims to provide both on-site and remote attendees with a spatial sense of co-location in the very same venue location, thus ultimately improving perceived presence.

CCS CONCEPTS

• **Human-centered computing** → *Interactive systems and tools.*

KEYWORDS

VR, MR, AR, mingling, hybrid conferences, mobile devices, distributed systems

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1 INTRODUCTION

Mingling, an activity where people engage in ad-hoc, private conversation, is essential to social networking at scheduled events like conferences. Thereby, people can get exposed to new sources of information [6, 8, 17], making such spontaneous interactions highly beneficial to human creativity and innovation. Mingling can be an opportunity for attendees to have deeper discussions on certain topics (e.g., a recent talk and presentation), to exchange ideas, to reconnect, or to find new contacts. Conference attendees mingle before, after, or during breaks. Mingling often takes place at ad-hoc venue spots, such as hallways or coffee-break corners.

After the Covid-19 pandemic, conferences are shifting from fully virtual to hybrid mode where attendees can either participate on-site at the conferences' physical venue or remotely using online communication tools. In such setting, on-site attendees can adequately benefit from mingling at the venue. However, remote attendees face a greater challenge in accessing on-site activity through communication tools that were primarily designed for pandemic-age virtual mingling, such as Zoom, WebEx, Microsoft Teams, or Slack. As we see it, it is cumbersome for on-site attendees to open an app on their phone, check whether there are anyone being online, and invite them to join an ongoing, on-site conversation. Undesirably, this might make remote attendees feel isolated in spite of their conference attendance. Due to this on-site remote disconnect, isolation can reduce networking benefits typically provided by mingling.

To help overcome this disconnection, in this on-going work, we introduce HybridMingler, a collaborative mixed reality (MR) system designed to improve the presence of remote attendees while mingling with on-site attendees at hybrid conferences. HybridMingler provides two interfaces: one for on-site attendees and one for remote attendees. These interfaces allow both types of users to perceive each other as spatially co-located within the physical conference setting. Making use of physical ambient displays, HybridMingler enables on-site attendees to be unobtrusively aware of the presence of the remote ones at the mingling spots like corridor, cafe corner to easily involve them into conversations. In this paper, we present the conceptual design and implementation of an early functional prototype of HybridMingler. This paper also outlines future prototype improvements and plans for systematic system evaluation.

2 RELATED WORK

In order to design HybridMingler, we examined various research works and implementations supporting ad-hoc conversations or enabling conference attendance in distributed settings. Thus, design considerations of HybridMingler could be established to mitigate the issues introduced above.

2.1 Telepresence for remote conference attendance

Even though hybrid conferences have become particularly commonplace following pandemic-age travel restrictions, certain remote-attendance approaches for in-person conferences were seen long before 2020. For example, at Ubicomp/ISWC 2014, Beams telepresence robots were deployed at the conference venue, allowing seven participants to attend the conference remotely [14]. Participants could access and control these robots via a software interface installed at their computer. Remote participants could thereby explore the venue's spatial environment, greet, and even start mingling with on-site attendees. This approach was later employed to support remote attendance at ACM SIGCHI 2016 [2] and 2018 [18]. By placing a proxy in the conference's physical space, remote participants reported a higher sense of immersion in the conference, especially in ad-hoc conversations with on-site attendees [14]. Compared to standard video conferencing, they reported communication and interactions being more directed to them [14].

However, these robots are rather costly (at least 1500 USD) and each can only be accessed by one remote attendee at a time. Therefore, this approach is challenging to scale in the era where hybrid conferences are becoming a new common setting and more participants will choose to remotely attend a conference. Apart from that, remotely navigating the telepresence robot around the conference's physical space was also sometimes reported to be challenging [14]. In addition to that, similar visual appearances of the telepresence robots also make remote attendees less personalized and individually differentiable to on-site participants [14], making it sometimes difficult to initiate engaged conversations.

2.2 Support for virtual mingling at conferences

Aside from using telepresence robots as physical proxies for remote attendees, there have been a number of interfaces supporting mingling among remote participants in virtual conferences. SharedSpace is a video-conferencing tool which attempted to provide remote participants with a sense of spatial sharing by replacing their video feeds' backgrounds by a virtual backdrop [7]. The topic of supporting mingling particularly received substantial attentions during the Covid-19 pandemic when the conferences were shifted to virtual settings. Minglr [17] is another video-conferencing-based mingling system for virtual conferences with match-making support. FluidMeet [11] enables smooth transitions between in-group, between-group, and private conversations in virtual coffee breaks by providing out-group individuals the ability of overhearing and allowing groups to control their context sharing. SpatialChat [1] aimed to improve the sense of spatiality and sociality in virtual mingling by placing the profile photos or video feeds of conference attendees on a background depicting different social spaces (e.g., a café, a chill-out room, or a terrace) and dynamically adjusting audio volume based on the distance between attendees' representations on the interface. Nevetherless, these solutions are more suitable for mingling at virtual conferences than at hybrid ones. At hybrid conferences, on-site attendees would not be likely to have time to access these virtual spaces and connect with remote participants. partially due to their focus on ongoing activities at the conference's venue. HybridMingler attempts to mitigate this by providing on-site and remote attendees the impression that they are co-located in the conference's physical venue. In addition to that, HybridMingler also subtly hints on-site attendees about the presence of remote participants in the space in order to stimulate potential conversations between them.

2.3 Improving co-presence in virtual meeting

To increase the sense of being co-present in the same place in virtual meetings, video-conferencing and online meeting interfaces have employed various designs to increase physical proximity between distributed participants. Online platforms like Sococo [16] or GatherTown [5] place participants' representations on a virtual map resembling a certain physical space, such as an office or a coffee shop, visually informing them who are virtually nearby to start a conversation if interested. GAZE-2 [19] offers a 3D virtual environment (VE) where each participant's video feed is represented on a cube whose orientation indicates whom the participant is talking to or what he/she is paying attention to. Likewise, conveying proximity and spatility to enhance mutual awareness in VEs for conferences were modeled and exemplified in the DIVE system [3]. HybridMingler also leverages a similar metaphor, integrated into a MR environment, to enable mutual awareness on spatial proximity and sociality among on-site and remote conference attendees.

2.4 Remote spatial sharing

Advancements in scanning technologies, such as the integration of light detection and ranging (LiDAR) into mobile devices like iPhone or iPad opened the opportunity for convenient spatial sharing in remote collaboration. DistanciAR [20] leverages the 3D scanning function enabled by LiDAR on iPhone and iPad to allow a person to opportunistically access the spatial environment of a remote collaborator for viewing or even authoring. HybridMingler also utilizes this commodity of mobile LiDAR to capture the spatial environment of a physical space for mingling and develop a MR system on the top of the captured 3D data, which provides the sense of spatial sharing among on-site and remote attendees.

3 DESIGN AND IMPLEMENTATION OF HYBRIDMINGLER

3.1 Design considerations

Based on the existing works in supporting virtual meetings, conference attendance and mingling that we examined, we derived a set of five design considerations (DC) for a system to support mingling among on-site and remote participants at hybrid conferences and scheduled events:

DC1: The system should provide both on-site and remote conference attendees with ***the perception of spatially sharing the same environment***. This should improve the sense of co-presence among them.

DC2: The system should enable ***mutual awareness on physical proximity and spatiality*** among on-site and remote attendees due to their important roles in initiating, joining and maintaining ad-hoc and opportunistic conversations. Likewise, spatial awareness on non-verbal communication, such as pointing or gaze (either conveyed through eye or face direction) also need to be supported to reduce communication efforts and increase perceived social presence [10, 12], which is needed in private conversations.

DC3: As remote attendees are not physically at the conference, it is crucial to ***make their presence subtly visible to on-site attendees***. This should not detach on-site attendees from the surrounding physical environment in order to keep them willing to connect with the remote.

DC4: The system should allow remote attendees to ***visually differentiate themselves from others and even depict their personality*** on their appearance. This should provide more means to engage attendees in mingling as they can easily recognize the others and even their interests, which will be useful for match-making.

DC5: The system should be ***capable to efficiently accommodate several remote concurrent participants*** to be spatially present at the conference's venue without requiring a substantial cost (e.g., as compared to using telepresence robots).

3.2 Design of HybridMingler

We conceptualize HybridMingler as a mingling hub that can be easily deployed at different areas of a conference's venue, such as a lobby, a chill-out corner or a coffee-break room and allow on-site participants to perceive remote ones to be virtually spatially accommodated in the space through a MR experience. HybridMingler system consists of three main interconnected components: physical meet-up hubs placed at different mingling spaces at the conference's venue, a MR interface running on on-site attendees' mobile devices like smartphone or tablet and a virtual reality (VR) interface running on remote participants' personal devices (e.g., PC, laptop or mobile devices) (Fig.1).

Physical meet-up hubs: These are tangible artefacts that can be deployed in different spaces at the conference's venue from a spot at a lobby, nearby a coffee machine at the coffee-break corner or on a table in a relax room. Each meet-up hub will serve as a landmark in the conference's venue which acts as a physical proxy for opening a portal to connect on-site attendees with remote ones, who are virtually present in the surrounding space of the hub. The meet-up hub will keep on-site attendees aware of the presence of remote ones in the space using ambient lights (DC3). We were inspired by previous works, which demonstrated the effectiveness of using light as an ambient cue to maintain social awareness among remote collaborators [4, 9, 13]. In our system, we adapt the use of ambient light to subtly convey not only the presence but also partially the spatiality of remote attendees to on-site participants (DC3).

A physical meet-up hub has a ring light circling around it. When a part of the ring light turns on, it indicates that there are some remote participants virtually and spatially present in the space in the corresponding direction. The light intensity indicates the proximity of the nearest remote attendee to the corresponding part of the ring. Thus, hypothetically, when looking at illuminating parts of the ring light and their luminosity, on-site attendees can have a glimpse of remote participants' presence and their position in the mingling space, relative to the meet-up hub.

VR enabled interface for remote attendees: This is a 3D interface for remote attendees to remotely participate a conference. While it is implemented to run on a head-worn display supporting VR, here, we target more widely used personal devices like laptop,

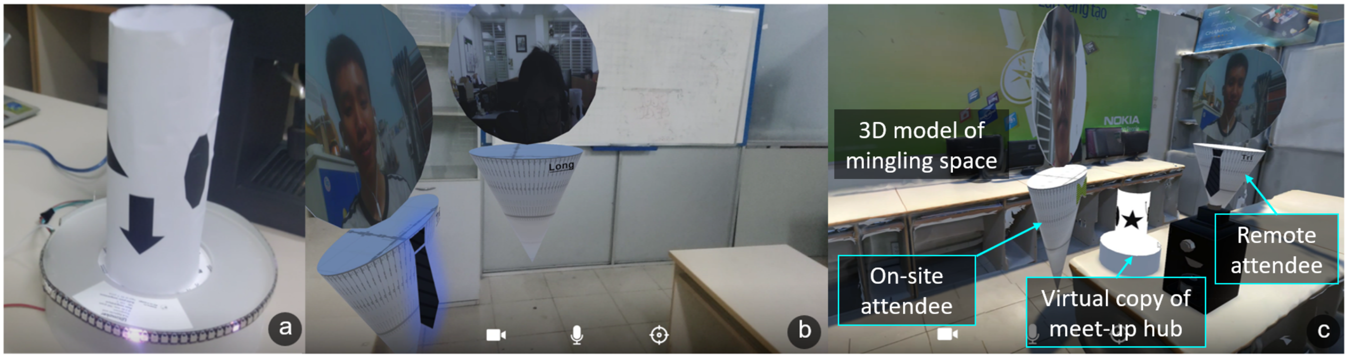

Figure 2: Components of current HybridMingling prototype: (a) the physical meet-up hub with LED lights illuminating indicating the presence of remote attendees in the mingling space, (b) the MR interface of on-site attendees showing a remote one virtually appearing in the direction of an illuminating LED light of the meet-up hub, and (c) the VR interface of remote attendees showing both other remote attendee and on-site one in the 3D scanned model of the mingling space.

desktop, laptop or smartphone. Independently of the device chosen, it shows the 3D model of the conference's physical venue providing user with the spatial experience of attending the conference. Users can freely navigate the VE for exploration, helping remote attendees picking up spatial cues of the venue, and thus consequently increase their sense of presence at the conference (DC1).

The VR system can also record remote attendee video feeds through the built-in front-facing camera of their personal devices, capturing the attendees' facial expressions (Fig.2b). The video feeds will be displayed on virtual 3D avatars, each presenting the corresponding remote attendee and spatially anchored at the attendee's position in the VE. Thus, on the VR interface, each remote attendee can see the virtual 3D avatars of all other remote attendees. We decided to use live video feeds to represent the attendees instead of using humanoid 3D avatars as the former can convey more realistic facial expressions. This can offer important non-verbal communication cues in engaged conversations like mingles. In addition to that, users can estimate the current attention of each remote attendee based on the facing direction of his/her video feed (DC2), which will change according to the facing direction of the attendee in the VE.

Moreover, to provide remote attendees with a sense of spatial co-presence with on-sites attendees, on-site video feeds captured by the MR interface (see next section) are also presented in the VE of the VR interface. The position of each on-site attendee's avatar in the VE is interpolated based on the on-site attendee's relative position to the meet-up hub at the physical venue, which is determined by the MR interface (to be detailed in the next section). Similarly, the spatial attentions of on-site attendees as estimated by the MR interface will also be reflected on the directions of their corresponding virtual avatars. Thus, when an attendee is talking to another in the VE, the avatar should be oriented accordingly, helping raise social awareness among them (DC2).

We also provide attendees with appearance personification for their appearance in the VE. Attendees can choose various graphical items, such as hat, tie, necklace, badge to customize their avatars. First, this allows them to the express their personality. Second, this should support attendees to easily recognize or differentiate between each other (DC4). To help quickly detect which attendees are speaking in the VE, especially from the back of their video feeds, we further add visual effects on these items (e.g., glowing, blinking) while speaking is detected.

To provide a high sense of spatial immersion, the VR interface also supports spatial awareness to enable overhearing among attendees. More particularly, a remote attendee can only overhear or talk to another in the VE when the Euclidean distance between them is less than 1.5 meters. This is to avoid noisy audio communication in on-line conference when users have to hear the sounds from people or sources out of their interest. Here we leverage the metaphor of using physical proximity to ensure that an attendee will only hear the audio signal of people close by or he/she is intentionally approaching. To provide spatial-aware perception of verbal communication between them, the closer to they are, the louder they can hear each other.

Mixed-reality (MR) interface for on-site attendees: This is a mobile interface acting the portal for on-site attendees to communicate with remote ones. We aimed to design it for mobile devices like smartphone or tablet as these commodity devices can be conveniently carried by attendees also anywhere and at anytime at a conference, including during mingling session. The main goal of this interface is to allow on-site attendees to perceive the presence of remote ones as if they spatially inhabit in the same physical space (Fig.2c). Therefore, we employed MR interactions for this interface. The main screen of the interface shows the live video feed captured by the rear camera of the user's mobile device. An on-site attendee will hold his/her device and use this interface to scan a physical meet-up hub. Once the physical meet-up hub is detected in the video feed, the interface will estimate the relative position of the on-site attendee to the meet-up hub and then his/her position in the physical mingling space. Based on this, virtual avatars of on-line remote participants will be spatially integrated on the live video feed at their corresponding position in the virtual world. The avatars' directions on the MR interface are aligned with the VR environment.

Beside using the rear camera to capture the venue's physical environment, HybridMingler also leverages the device's front camera to record the video feed of the on-site attendee, which will be displayed on the VR interface of remote participants. The position of the on-site attendee's video feed in VR is determined based on his/her relative position to the meet-up hub in the venue's spaces. Similar to the VR system, the MR interface also supports spatial awareness to enable overhearing between on-site and remote attendees as well as physical-proximity audio rendering between them.

3.3 Scenarios of use

We demonstrate how on-site and remote attendees interact with the three component interfaces of HybridMingler to engage in hybrid mingles in the following three exemplary scenarios:

Scenario 1: an on-site encounters a remote
Bob is physically attending a conference. Meanwhile, Alice is remotely participating the same conference from her home, via the VR interface of HybridMingler as recommended by the conference's organizer. It is break time after a presentation session and Bob is sitting on a sofa chair at a chill-out corner to relax. At the same time, Alice also takes this free time to virtually explore the conference's venue and she is also passing by the chill-out corner. At the physical chill-out corner, Bob notices that there is a meet-up hub placed on a coffee-table next to the sofa chair Bob is sitting on. The meet-up hub attracts his attention by some illuminating light on it which are turned on when there are some remote attendees present in their direction, ambiently stimulating awareness of on-sites like Bob. He sees an instruction on the hub telling him to scan it using the HybridMingler application that he already downloaded to his phone following the recommendation of the conference's organizers. Because he is very curious about the illuminating light, he follows the instruction, opening HybridMingler on his phone and pointing the phone' rear camera to the hub to scan it. Once, the hub appears in the camera's video feed shown on the phone's screen, Bob can see the video stream of Alice spatially located in the tea-break room in the direction of the blinking light. Bob remembers that Alice asked an interesting question in a presentation he was listening to yesterday. He walks closer to Alice to say "Hi" and they start to chat about several things relevant to the presentation.

Scenario 2: multiple on-sites engage a remote in a mingling group:
Bob and Caroline are on-site attendees at the conference. It is break time and they are chatting with each other in the conference's tea-break room. They are standing next to the coffee table, having some coffee and talking about some research ideas. There is a meet-up hub placed on the top of a coffee machine nearby them. The notice some lights on the hub orienting towards them are blinking with a high brightness. They are wondering if someone nearby, so both use their phone to scan the hub with the HybridMingler application. Through the MR interface of HybridMingler, they see Anthony, who is remotely attending the conference, virtually located close by. Sitting at home via the VR interface, Anthony also notices the appearance of Bob and Carol and their attention on him. They greet each other and Anthony realizes that he has been also aware of what Bob and Caroline were talking about. He thus provides some input and they continue elaborating on the research ideas.

Scenario 3: an on-site joins a conversation of multiple remotes:
Catherine is an on-site attendee. It is break time and she is standing alone at a corner in the tea-break room. She does not have any colleagues attending the conference with her. Also, she does not know many people here. She is thinking that she might only stand here, enjoy a cup of coffee, look at people around her and wait for the next session. Suddenly, she notices a number of illuminating lights on a physical meet-up hub placed next to a plan pot nearby. She scans it with the HybridMingler application to see who is around. Through the MR interface, she sees Daniel and Erik chatting with each other, both are joining remotely from their homes, respectively Canada and Philippines. Caroline immediately recognizes Daniel as she has read several research articles co-authored by him and even visited his webpage. Meanwhile, Daniel and Erik are aware of Catherine' presence on their VR interface. Through the MR interface, Catherine approaches and say "Hello" to both, especially telling Daniel that she really likes his research. Daniel was a bit surprised but then warmly thank and involve her to the ongoing conversation with Erik.

3.4 Early Functional Prototype

In this section, we describe the implementation of a functional prototype of HybridMingler.

Physical meet-up hub: In the current prototype, for the sake of simplicity, we crafted a physical meet-up hub as a cylinder (30-cm height, 10-cm diameter) textured by visual patterns which allow different parts of the hub to be accurately recognizable using computer vision. We chose to use a cylinder rather than other shapes, such as a cube or a hexagon prism because in several tests in the prototyping process we found that the curved surface of a cylinder resulted in better recognition and tracking in 3D than edged shapes (Fig.2a).

The hub's ring light was constructed from a strip of 90 LED units circling around the cylinder (Fig.2a). Each unit thus corresponds to a 4-degree angular area around the hub. The color and luminosity of each LED unit can be programmatically configured. Each LED unit has 16777216 color possibilities (3 channels, 256 values per channel) and 256 level of luminosity. We have tested several color options and decided to use white color (R = 255, B = 255, C = 255) to encode the presence and spatiality of remote participants. We found that this color seems to be easiest to visually differentiate luminosity levels. To further support easy differentiation of luminosity, the LED brightness is divided into four levels (6, 15, 70, 255), respective to four distance thresholds from the meet-up hub, which are 0.5, 1, 1.5 and 2 meters. The LED strip is connected to, powered by, and controlled by an Arduino Uno R3 board.

VR interface: The VR interface was developed using Unity. To quickly create a realistic 3D environment of a mingling space, we used an iPad Pro 12 supporting LiDAR to scan a meeting room (W: 3.5m x B: 3.5m x H: 3m) in our university. The scanned 3D data was briefly manually processed in Blender to fill scan holes and trim irrelevant details (Fig.2b). We used this method instead of manually modeling the 3D space of the venue due to two reasons.

First, leveraging off-the-shelf mobile 3D scanning is much more cost efficient. Second, although the appearance of the 3D scanned data does not look smoothly polished, it still provides more a realistic representation of the venue than a manually crafted 3D model. In addition to that, we also would like to demonstrate the feasibility of rapid prototyping for HybridMingler using consumer-market technologies. Network communication for video conferencing was implemented using Unity Photon framework due to its high performance and reliability [15]. We also added a pointing feature for remote attendees to spatially refer to a position in the mingle space easily.

MR interface: The MR interface was implemented using Unity and Vuforia SDK. A 3D model of the physical meet-up hub with its texture was fed into training in Vuforia for spatially detecting and tracking the hub. Besides that, ARcore was also integrated to track the device position and orientation spatially even when the meet-hub is not in the field of view of its camera. Similar to the VR interface, Unity Photon was used in the MR interface to handle network communication. The Vuforia SDK supports MR tracking using both imaging features from the camera as well as inertial sensors' data. Thus on-site attendees do not need to scan the physical meet-up hub all the time. They might just need to scan it only once and then HybridMingler MR system will automatically track the device's movements, even when the meet-up hub is out of the camera's field of view, to estimate its current position. Therefore, if a remote attendee is positioned a bit far from the meet-up hub in the VE, on-site attendees can still see them in the physical mingling space through the MR interface. At the moment, the system can concurrently stream and display up to fifteen live video feeds of remote attendees with a frame rate of 25 frame per second, which does not cause noticeable latency in video conferencing. To further optimize the performance (i.e. reducing the latency of remote attendees' video feeds), the MR interface only renders the live video feeds of remote attendees who are currently within the field of view of the on-site attendee (currently set at 90 degree horizontally and 60 degree vertically) and at a distance less than 2m from the on-site one.

4 FUTURE ADVANCEMENTS AND EVALUATION

The current design and prototype of HybridMingler might be effective at facilitating mingles between remote attendees or provoking an on-site to proactively approach and engage remote participants into conversations. The reason is that remote attendees might be more frequently available in the VE than on-site attendees, who will not always open the HybridMingler system when being at the conference's venue. When an on-site attendee is not opening the HybridMingler application, remote attendees cannot be aware of their presence in the space. Therefore, in order to foster remote attendees' proactivity in establishing mingles with on-site ones, additional sensors, such as surveillance cameras might be installed at mingling corners in the future to detect the presence of the on-sites and visualize them on the VR interface.

To evaluate HybridMingler, we foresee to deploy the system at a conference that will be organized at our university in July 2023. We will collect different usage metrics of the system, such as how many remote/ on-site attendees have used the system, how often and how much time they spent on it, how many mingling sessions have been established over the entire conference period or how proactive remote/on-site attendees are in initiating conversations. Additionally, we will also conduct interviews with conference attendees to gather qualitative insights on the effects of HybridMingler on their experience, perception, and behavior.

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