MR4ISL: A Mixed Reality System for Psychological Experiments Focused on Social Learning and Social Interactions

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ABSTRACT

We present MR4ISL (Mixed Reality for Implicit Social Learning), a HoloLens application designed to examine the psychological aspects involved by *implicit social learning*, a key process responsible for information acquisition at an unconscious level that influences humans' behavioral, cognitive, and emotional functioning. We describe the engineering details of MR4ISL, present our roadmap for identifying technical solutions for believable animations of virtual avatars relevant for implicit social learning, and exemplify use cases of MR4ISL that emerged from discussions with three researchers from psychology. To date, MR4ISL is the only tool that uses mixed reality simulations to increase the external validity of psychological research in the study of implicit social learning.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile devices**; **Mixed / augmented reality**.

KEYWORDS

Mixed Reality, HoloLens, implicit social learning, unconscious cognition, tool, software architecture, engineering interactive systems.

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1 INTRODUCTION

One of the major challenges facing current paradigms in Cognitive Psychology research is the extent of their external validity [31], i.e., whether a laboratory-based evaluation of a cognitive ability represents a good proxy for the functioning of that ability in the real world [16]. Following researchers' legitimate desire to control the independent variables of their studies as strictly as possible, studies typically resort to employing stimuli that are as simple as possible, carrying neutral, reduced motivational and/or emotional significance for the study participants. A negative side effect of this attention to precision, controllability and, consequently, artificialization of experimental research in psychology is the fact that it is not known to what extent data collected from such studies are relevant to the phenomena of everyday life.

Augmented and Mixed Reality (AR/MR) applications enable researchers with the possibility to expose the participants of their studies to life-like interactions while maintaining the desired level of experimental control over the various aspects involved by their studies. For instance, Pamparău's [21] HoloLens-based MR system implementing a 3D desktop interaction metaphor was presented to a diverse public to collect perceptions about the intuitiveness of the concepts it introduced. FlexiSee [24], another HoloLens-based application designed for flexible configuration, customization, and control of mediated vision from a distance, was validated in an experimental setting with remote participants acting as "vision assistants" and "vision monitors" for the primary user wearing the HoloLens head-mounted display (HMD), enabling the transition from "do you see what I see?" to "do you control what I see?" functionality for MR [22]. Other examples where mixed reality has supported studies in psychology are available [4,12,19,20].

In this work, we introduce MR4ISL (Mixed Reality for Implicit Social Learning), the first application employing MR to support research and scientific experiments in the area of Implicit Social Learning (ISL), the key process of information acquisition, running at an unconscious level, that influences humans' behavioral, cognitive, and emotional processes and functioning [27]. To this end, MR4ISL follows the principles of implicit and explicit learning of socio-emotional information [7], and implements voice and gesture-based input to enable users (participants in controlled studies and experiments) to interact with virtual avatars in mixed reality. In this paper, we present the technical details of our implementation employing the HoloLens HMD, describe our roadmap for identifying appropriate technical solutions for photo-realistic avatars with believable animations for studying ISL, and present several use cases from discussions with three psychology researchers.

2 RELATED WORK

We discuss prior work on AR/MR applications developed to support research in psychology. We also present an overview of ISL, an area of scientific investigation from psychology for which very little tool support has been provided in the scientific community and which our MR4ISL application addresses directly.

2.1 Augmented and Mixed Reality Applications and Tools to Support Studies in Psychology

Several applications and systems have been proposed in the scientific literature to support research in psychology with AR/MR concepts and technology. For example, Leader [12] referred to Mixed Reality Therapy as *"the deliberate use of mixed reality in an extended therapeutic context [...] to create learning environments that are conducive to therapeutic progress"* (p. 217). In the following, we overview prior work in this area.

Oduola *et al.* [19] introduced an MR system for evaluating empathy, building on the motivation that severe deficits in empathy can be observed in several personality disorders, psychopathy, and autism. Their system used HoloLens to present users with 3D virtual content and to enable interactions via speech, gesture, and eye-based input. Omedas *et al.* [20] developed the eXperience Induction Machine engine (XIM-Engine), a biologically-inspired software framework for capturing and analyzing multimodal human behavior in an immersive environment. The framework enables researchers to conduct psychological studies about both conscious and unconscious reactions in relation to interactive systems. The engine integrates the XIM machine [4], an immersive MR room equipped with sensors, visualization, and sonification systems.

A few systems have combined MR and brain-computer interfaces (BCIs). For example, Potts *et al.* [26] introduced ZenG, a neuro-feedback application concept based on zen gardening, to foster creativity, self-awareness, and relaxation through embodied interactions in MR. (Neuro-feedback is a technique used for the treatment of various psychological and neurological conditions [1]). ZenG combined physiological sensing (electroencephalography) with mixed reality visualizations provided by the Magic Leap device. Neo-Noumena [30], a communicative neuro-responsive system, employs a BCI to detect users' emotional states and represent them in MR. Thus, the system can augment interpersonal emotion communication through MR with visual representations of dynamic fractal shapes, representative of users' emotional states.

2.2 Implicit Social Learning

A number of studies [18,28] have argued that humans often engage in complex behavioral patterns in daily life without having conscious access to the procedural knowledge that guides them during those behaviors. The results of these studies suggest that such behaviors are based on a learning process that occurs *implicitly*. One of the most frequently mentioned categories of such behaviors is inferences about other people's mental and/or emotional states that are plausibly guided by knowledge that has been acquired unconsciously. For example, we can often infer when a person is sad or angry from the tone of their voice or their body posture, without being aware of how we gained that information [18].

Such *implicit learning* denotes the acquisition of information that is not conscious, but that nevertheless influences our behavioral, cognitive, and emotional processes and, consequently, it can be described as *implicit social learning* (ISL) [27]. While the potential relevance of unconscious learning for social functioning has been repeatedly suggested in the psychological literature over the past decades [11,18], the experimental tasks that have been used for investigating it are still highly artificial and unrepresentative of real-life social phenomena, i.e., the external validity for the social domain of current experimental settings is under concern. For instance, existing methods expose participants to graphical patterns composed of sequences of letters or dots [17,27], which have little meaningfulness with respect to the events and phenomena characteristic of everyday life. Since ISL is key to the understanding of humans acting in the real world and interacting with other humans, appropriate methods and tools to support observations and research in implicit learning are paramount. However, in the context where existing experimental paradigms use only neutral and artificial instead of social and emotional stimuli, experimental research struggles to advance towards connecting implicit learning with the acquisition of socio-emotional abilities.

3 MR4ISL SOFTWARE ARCHITECTURE AND TECHNICAL IMPLEMENTATION

Figure 1 illustrates the software architecture of MR4ISL, our MR application for HoloLens for studying implicit social learning. The MR scene, unfolded on the entire physical world around the user as covered by the world scanning capacity of the HoloLens HMD, contains one avatar with a set of predefined animations that are activated depending on the input, either speech or gesture-based, received from the user, participant in an experiment or study. Thus, the various components of our application address the rendering of the avatar and voice and gesture recognition, respectively.

We implemented MR4ISL using the first generation HoloLens HMD featuring a 32-bit Intel architecture, 64 GB flash and 2 GB RAM memory, and running Windows 10. We used Visual Studio 2017, Unity3D, and the Windows Software Development Kit for Windows 10 to implement MR4ISL as a C# Universal Windows Platform (UWP) application. We also used the Compute Engine Virtual Machine[1] and Google SpeechToText (STT) API from Google Cloud Services, and Node.js for our server component; see Figure 1. Gesture recognition was implemented with the HoloLens built-in technique for detecting *bloom* and *air-tap* gestures.[2] Our goal for MR4ISL was to recognize speech input in the participants' native language. However, the first generation HoloLens employed for our prototype recognizes only English commands, while the second generation does not provide support for all languages. Thus, we

[1] *ubuntu-1804-bionic-v20201014* image, 2 vCPUs, 4 GB memory
[2] HoloLens 1 gestures for authoring and navigating in Dynamics 365 Guides, https://docs.microsoft.com/en-us/dynamics365/mixed-reality/guides/authoring-gestures

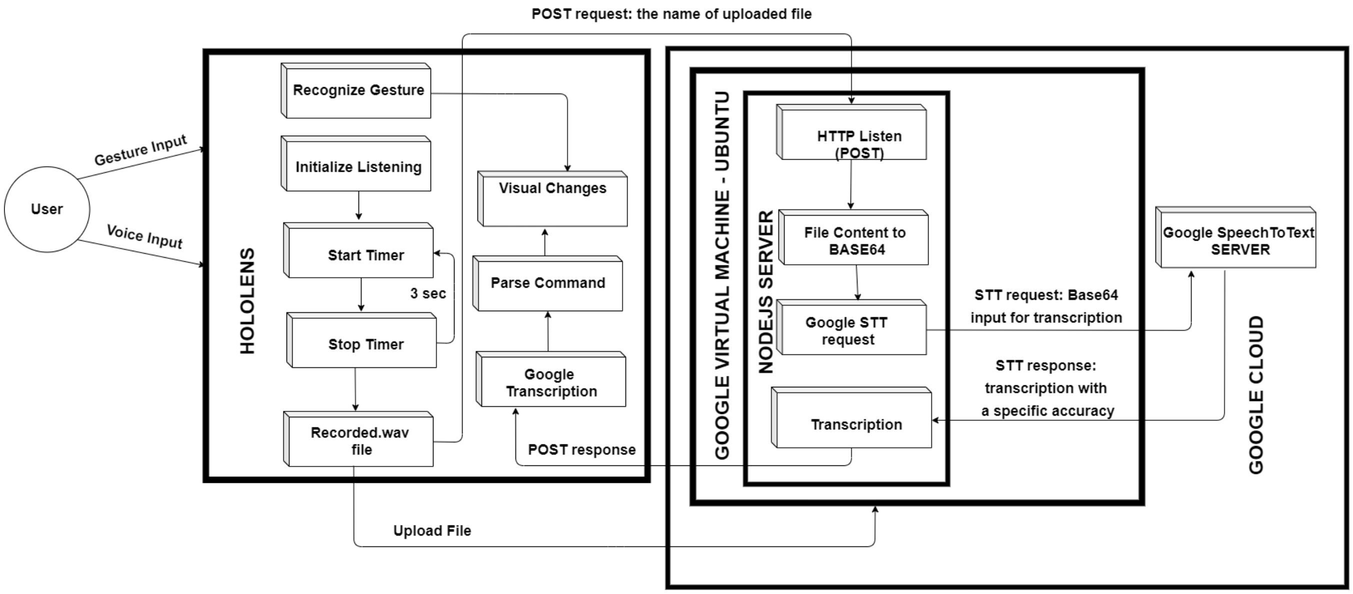

Figure 1: Software architecture diagram of the MR4ISL HoloLens application.

designed our solution around the Google Cloud STT API, for which we implemented a Node.js server to handle all the communications between HoloLens and external services. Thus, audio data, captured from the built-in microphone of the HoloLens HMD as a *wav* file, is sent to the Ubuntu Virtual Machine via POST, converted to Base64, and processed by the STT API with specified settings (i.e., two audio channels, 48,000 Hz sampling rate, and LINEAR16 encoding); see Listing 1 for an example. The recognized text is compared via the Longest Common Subsequence (LCS) with keywords from our dictionary and, if the percent of the match is larger than 75%, an empirically determined threshold during our testing trials, a new animation is played for the virtual avatar. In our testing, the latency of using Google services was barely noticeable, below one second.

Listing 1: Node.js code snippet from the server application running on the Ubuntu Google Cloud Virtual Machine.

```
const http = require('http');
http.createServer((request, response) => {
  if (request.method === 'POST' ) {
    let body = [];
    request.on('data', (chunk) => {
      body.push(chunk);
    }).on('end',async () => {
  body = Buffer.concat(body).toString();
  const speech =require('@google-cloud/speech');
  const fs = require('fs');
  const client = new speech.SpeechClient();
  const file = fs.readFileSync(body);
  const audioBytes = file.toString('base64');
  const audio = { content: audioBytes };
  const config = {
   audioChannelCount: 2,
    encoding: 'LINEAR16',
    sampleRateHertz: 48000,
    languageCode: 'ro',
  };
  const req = {
    audio: audio,
    config: config,
  };
  const [resp] = await client.recognize(req);
  const transcription = resp.results
    .map(result => result.alternatives[0].transcript)
    .join('\n');
 response.end(transcription); });
  } else {
    response.statusCode = 404;
    response.end();
  }
}).listen(8000);
```

The photorealism of the virtual avatar and its animation represent distinctive features of MR4ISL that, unlike prior methods employed for studying ISL (i.e., sequences of graphical patterns; see Section 2.2), contribute to increasing the external validity of psychological experiments to observe participants' behavior in relation to implicit learning in social contexts. Therefore, to arrive at the best option for our purpose regarding the implementation of the virtual avatars and their animations, we tested various options, which we briefly overview in the following to illustrate our roadmap for the benefit of other practitioners. Character Creator[3] (Figure 2, top left) is a software platform that conveniently implements avatars downloadable as *.fbx* files, which can be easily imported into Unity and rendered in a HoloLens application. However, the price of the license was high for our practical needs and the free-trial 30 days period was limited to just ten downloads. The MakeHuman[4] platform (Figure 2, top right) enables the design of virtual characters from scratch, which can be afterward imported into Character Creator to attributing them specific animations. However, the platform provides few functions to customize the avatar at the level of detail needed for our goal. Finally, we employed Adobe Mixamo,[5] (Figure 2, bottom) a web-based application consisting of a collection

[3]https://charactercreator.org
[4]http://www.makehumancommunity.org
[5]https://www.mixamo.com

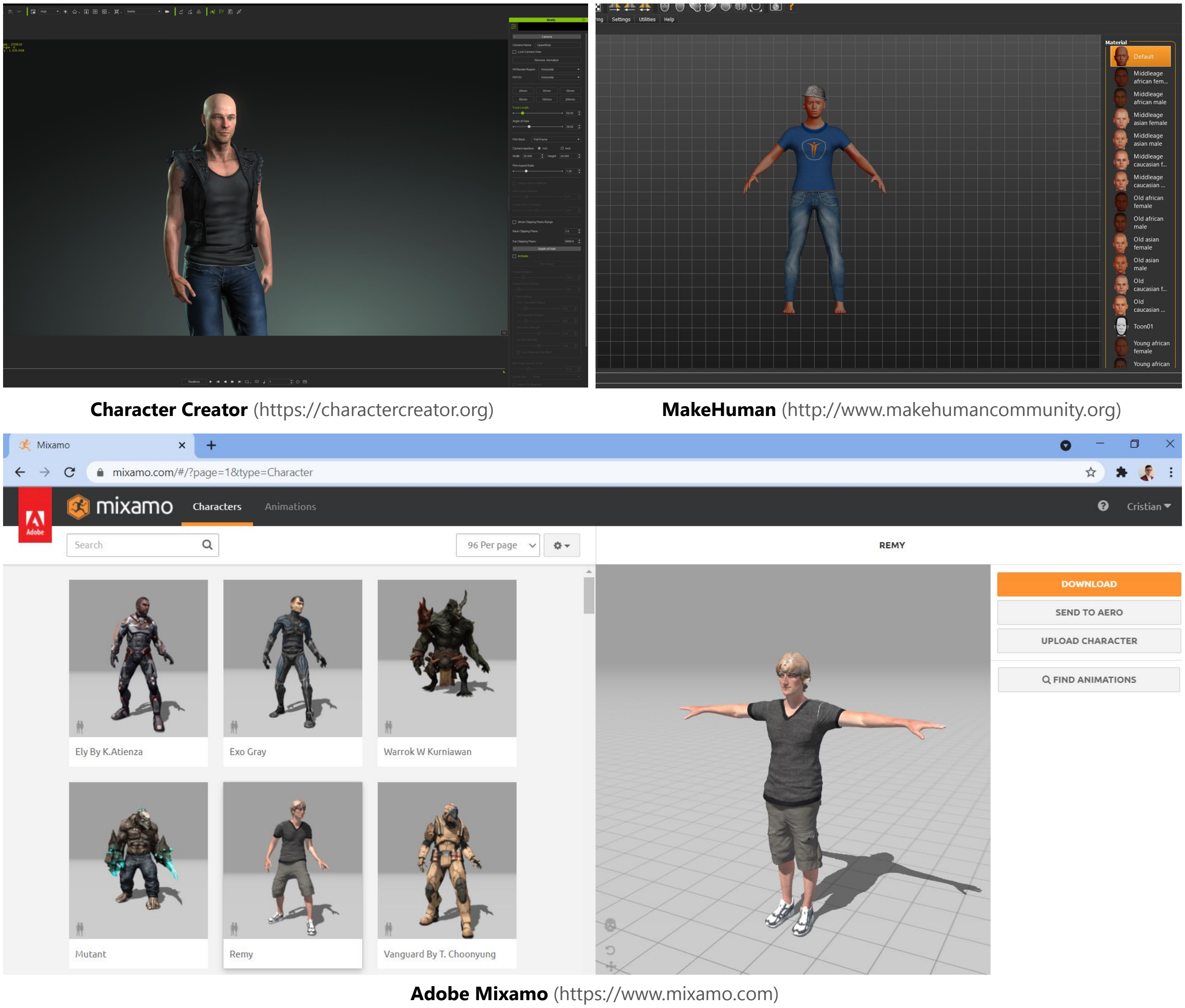

Figure 2: Our roadmap for identifying virtual avatar animations relevant for implicit social learning. The virtual avatars from these images were specified with Character Creator, MakeHuman, and Adobe Mixamo, respectively.

of more than one hundred virtual characters and two thousands predefined animations, including characters and animations that are relevant for real-life situations and social interactions and, consequently, to the scope of MR4ISL for studying ISL.

4 USE CASES, DISCUSSION, AND LIMITATIONS

Figure 3 depicts different states of two virtual avatars anchored on the floor of a physical room and displayed at the height of the user (a participant in a controlled experiment or study). The participant is introduced in the mixed reality space of MR4ISL and exposed to several dance moves performed by the virtual avatar according to a set of rules, such as from [29]. In subsequent tasks, the participant is exposed to other dance moves that either follow the rules or not. If the participant is accurate in discriminating the moves that follow the rules from those that violate them, while at the same time being unable to describe those rules, the researcher or the clinician may conclude that implicit social learning has occurred.

We presented MR4ISL to three researchers from psychology (with experience of 23, 6, and 4 years, respectively) to get preliminary feedback, but also to inform further design and other use cases. The researchers identified several use cases for MR4ISL to support studies in the area of implicit social learning as circumscribed in the general field of psychology and, respectively, in the sub-field of cognitive-behavioral psychotherapies [3]. In general psychology,

Figure 3: Two animated virtual characters rendered by MR4ISL at the height of an adult and anchored to the floor of the physical room. The top images illustrate the social situation of a person dancing; the images from the bottom show pointing, another commonly encountered behavior.

MR4ISL opens avenues for investigations regarding the ecological, real-life aspects of implicit learning, e.g., it can be used to investigate whether ISL can predict various aspects of social adaptation. For example, researchers could test whether implicit learning is involved in the acquisition of social skills or whether it predicts the quality of social relations. Psychological interventions are comprised of two components: (a) an assessment process followed by (b) the actual intervention, both discussed next.

During the assessment process, the psychologist collects as much relevant data as possible using interviews, questionnaires, behavioral tasks, etc. The objective of this step is for the psychologist to develop an informed opinion about the patient's psychological functioning, which often serves as the knowledge basis for the diagnosis. Regarding ISL, previous empirical studies [8,10] have argued that clinical psychological disorders that are characterized by social functioning deficits, such as autism spectrum disorders, depression, or bipolar disorders, could be explained, at least partially, by a deficit in ISL. If the dysfunction of ISL is manifested in multiple disorders, the process can be characterized as trans-diagnostic. So far, however, because of the limitations of ISL paradigms capable of inducing and/or measuring the social dimension of implicit learning, this hypothesis could not be adequately investigated. MR4ISL enables the opportunity to overcome this obstacle, thereby becoming an instrument for testing this hypothesis in ways not possible before. Its applicability is as wide as the psychological disorders that are characterized by an impaired processing of socially relevant information. For instance, MR4ISL can be used to investigate, both in scientific studies and in assessing individual cases, whether patients with various mental disorders manifest deficits in ISL.

During the intervention process, the psychologist changes their focus and attempts to alleviate the patient's psychological functioning and/or well-being by targeting specific processes or problems identified during the evaluation. Various techniques are available at this stage, such as cognitive restructuring and behavioral experiments [3]. Although MR4ISL was designed as an assessment tool, it could potentially serve as a technical scaffold for the development of curative interventions. As a prospective use case, it is often argued that individuals with autism spectrum disorders cannot learn social rules because they cannot properly perceive the intricacies of human facial expressions [6,9]. By capitalizing on the versatility of MR technology, MR4ISL could be adapted to expose participants to facial expressions that gradually increase in complexity as progress is achieved during therapy.

4.1 Limitations

One limitation of MR4ISL is represented by the fact that we designed our system for interactions with one virtual avatar at a time. Placing more avatars in the MR scene would enable more possibilities for designing experiments about implicit social learning, where more complex social situations involving groups of people (the participant and the virtual avatars) could be simulated and investigated. Adding more virtual objects in the MR scene while moving along the Reality-Virtuality continuum [15] would enable studying of even more complex scenarios, e.g., where virtual objects, such as a physical TV set in virtual reality [32] or a virtual TV in augmented/mixed reality [25], mediate social communication and interaction, or create a specific type of a social environment.

Besides speech, MR4ISL users can interact with the virtual avatars using gestures. Air-tap, a default gesture in HoloLens, can be performed on a virtual object once that object has been fixated with the eye gaze. Although air-tapping is convenient since it is available by default, prior work [5,13,14] reported it being difficult to use. For instance, Aruanno *et al.* [2], who described a system for people with neuro-developmental disorders, proposed two alternatives: allow a period of familiarization for users to learn the gesture, a solution also considered in [33], and replacing the default cursor (a small disc) with a hand icon with audio feedback. Another solution could be represented by an external gesture sensor, for which we considered Kinect and pointing gestures, and a dedicated application to deliver the gesture recognition result to MR4ISL.

Other limitations regard our use of the first edition of HoloLens during development. Porting MR4ISL to other HMD models and platforms, such as HoloLens 2 in the context of mixed reality and HTC Vive for studying ISL in virtual reality environments, will enable a better experience for users in terms of the field of view (e.g., 110 degrees for HTC Vive vs. 34 degrees for HoloLens 1 and 54 degrees for HoloLens 2) and resolution (2048×1080 for HoloLens 2 vs. 1280×720 for HoloLens 1) for observing the behavior of the virtual avatars. Integration between MR4ISL and virtual reality is especially interesting in the context of eXtended Reality (XR); see the next section for more future work opportunities.

5 CONCLUSION AND FUTURE WORK

We presented MR4ISL, an application that employs mixed reality to support scientific experiments and research on implicit social learning. Moreover, MR4ISL is the only tool that presents real-life relevance for ISL research. Future work will focus on applying

MR4ISL in a multi-modal experiment design to facilitate the evaluation of implicit learning in psychological conditions characterized by impaired social functioning, such as autism spectrum disorders and depression. Moreover, future work will implement our system for therapeutic settings to attempt optimization of the functioning of implicit social learning for various disorders. Further technical developments of MR4ISL, such as a virtual reality use case scenario as a control condition for psychology experiments and therapeutic procedures as well as understanding the user experience [23] of interacting with virtual avatars in MR4ISL, are also envisaged.

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