GoNature AR: Air Quality & Noise Visualization Through a Multimodal and Interactive Augmented Reality Experience

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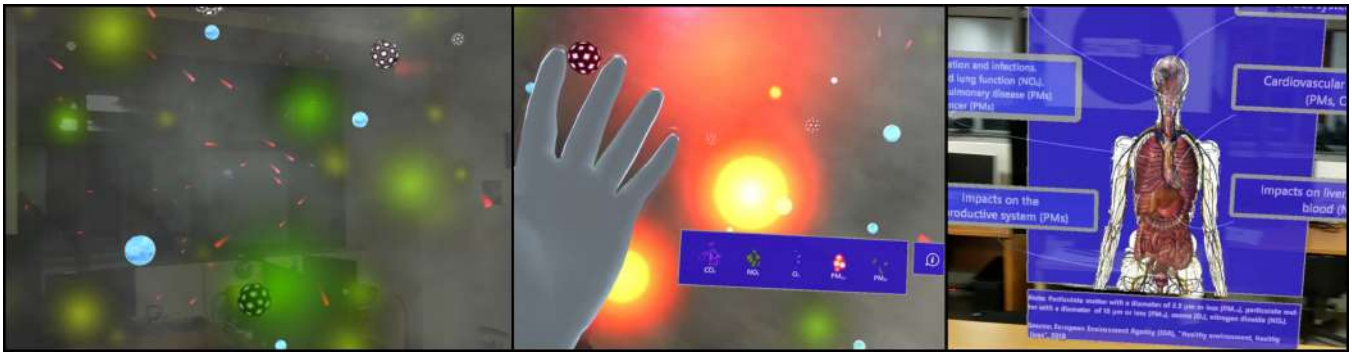

Figure 1: GoNature AR: Particles and gasses (left), On-hand info menu (middle), Health issues based on various pollutants (right).

ABSTRACT

As Extended Reality (XR) media experiences become a commodity, there is a unique opportunity to deploy XR for environmental awareness. Interaction challenges of Augmented Reality (AR) still exist, focused on limited gesture and head tracking affordances. AR technologies should also be seamlessly integrated with sensor data, analytics and ultimately status prediction, to be visualized in an AR experience, rather than merely superimposing visuals onto the real world. This paper presents an innovative, work-in-progress, multimodal AR experience integrating interactive narration, gestures, hands recognition and voice commands, while a citizen is wearing a head-worn AR display, promoting environmental awareness, health, and wellness. By combining AR technologies and a sensor network, GoNature AR provides citizen awareness of real-time, multimodal, air and noise pollution data.

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CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**;
• **Applied computing → Interactive learning environments**.

KEYWORDS

Augmented Reality, Multimodal, Hololens, Interactive Narration, Environmental Awareness

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1 INTRODUCTION

Extended Reality (XR) offers awareness of environmental conditions often disregarded [3]. Augmented Reality (AR) enriches the real-world with digital information [16] deployed on mobile devices and head-worn displays [8]. Digital media creators experiment with head-mounted AR sharing truthful stories [4], [11], [19], [5], [7]. Interaction challenges associated with AR still exist, focused on limited gesture-based and head tracking affordances [12]. AR technologies should be seamlessly integrated with sensor data, analytics and ultimately status prediction rather than merely superimposing visuals onto the real world. Audio augmented reality (AAR) is

relatively unexplored, enhancing audience engagement [10],[25] blending audio into the physical world to augment the user's real-world acoustic environment. However, it encompasses perceptual challenges when operating in outdoors, busy environments.

Extreme urbanization and hazards such as air and noise pollution are linked to negative effects on health and well-being [9]. The presence of air pollutants like NO_x, CO_2, O_3, SO_2, $PM_{2.5}$, and PM_{10} has been shown to have direct physiological health effects [17]. Noise pollution is a growing problem in urban areas, with over 20% of the European Union's population exposed to noise levels above 65 dB, which can lead to stress-related psychological symptoms [6], [13]. A countermeasure to these phenomena proved to be the promotion of greens spaces [9]. However, the positive effects of green spaces on the health and well-being of individuals are not widely understood by the general public.

In this paper, we present an innovative head-worn AR experience engaging and sensitising citizen communities around environmental issues such as air and noise pollution and the effects of such phenomena on human health and well-being (fig. 1). AAR is deployed, for the first time, to raise awareness of noise pollution. The system utilizes a network of internet-of-things (IoT) sensors to gather air quality data (NO_x, CO_2, O_3, SO_2, $PM_{2.5}$, and PM_{10}) and noise (dB) that adjusts the VFX particles system, audio effects and music or sound components of the AR experience. Non-visible phenomena are visualized such as pollution particles concentration, and city noise levels based on sensors' data deploying visuals and sound. Our paper proposes an innovative approach comprising of three key contributions:

- An innovative, head-worn AR system for noise pollution visualization putting forward a scalable design, offering an interactive AAR experience that dynamically adapts to environmental conditions in real-time using IoT.
- Air pollution visualization utilizing both multimodal input: gesture, hands, voice commands and multimodal output: visual and acoustic.
- An exploration of the potential of AR technology to sensitize citizen communities on air & noise pollution and their effect on human health and well-being, using both visual and audio augmentation.

2 RELATED WORK

Augmented Reality (AR) has the potential to motivate health and well-being behavioral change, yet to be explored. A recent review showed that 84% of XR interventions successfully altered behaviour [18]. In [21], a mobile AR system for flood visualization in outdoor environments has been implemented, however, it required a mobile device for GPS retrieval. IoT and AR have been combined to visualize air pollution [14], [15], [23], [20], [22] on a mobile platform. Marker-based mobile AR applications utilized a custom sensor kit gathering temperature, humidity, and particulate matter (PM10, PM2.5 and PM1.0) data [14], also communicating industrial pollution [22], however, user experience assessments were limited. Marker-based AR cannot be used widely, especially outdoors and provides limited interaction as users' hands are holding the mobile device. A custom IoT infrastructure is deployed in a mobile AR experience [20] to inform citizens about air pollution. An avatar's outfit was dynamically altered based on temperature and CO_2 concentration. The app does not involve the user, therefore, interaction is limited. Air particles have been visualized derived from data retrieved from an open platform [23], however, virtual particles are merely visualized on a screen without any interactivity. 12 different types of air pollutants using data collected from open weather stations were visualized [15] on mobile AR. However, data was not up to date, and the visualization was limited to a specific location with no other scenarios available for comparison. Users could only interact with it by tapping on the screen with their fingers. These limitations indicate a need for improvement of real-time data collection from sensors and related visualization methods so that user interactivity is enhanced. Head-worn AR, in our system, offers an immersive experience and seamless multimodal interactivity based on hand gestures, voice commands, speech and gaze-based interaction.

3 DESIGN AND IMPLEMENTATION

The proposed system will be used by citizens of multiple European cities in the scope of the VARCITIES European project [2]. GoNature AR is a multimodal AR narration story implemented for the Hololens 2 device guiding the audience through an immersive audio-visual experience, in which the user becomes aware of environmental phenomena and their consequences on human health & well-being.

3.1 Design & User Experience

The experience is divided in separate steps enabling development changes on each step independently as shown in fig. 2. The initial step involves new users, without prior experience with the Hololens 2 device. A brief tutorial introduces them to interaction methods within the experience such as gestures, voice commands and gaze input. In the next step, the narrative commences with

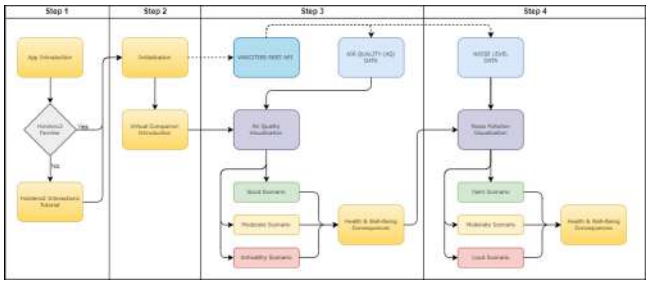

Figure 2: GoNature AR: Design Flowchart

an initialization phase. The system requests authentication and is ready to also request available environmental data from the server derived from sensors. A virtual companion is introduced to the citizen, at this point, to provide comprehensive guidance throughout the experience.

In step three of the experience, the app retrieves air quality data using the VARCITIES REST API and IoT infrastructure [24]. The end-user views a visual representation of the surrounding air quality and is provided with audio effects indicating the presence of particles and gases. Virtual pollution particles will obstruct the

user's Field of View (FoV) and float around them (fig. 3). The density of these particles will increase proportionally to the higher readings obtained from the air quality sensor. The end-user is informed about the air quality level and potential health implications. Depending on the current scenario being displayed (good, moderate, unhealthy), the citizen will be directed to the remaining scenarios not selected for comparison.

The final step focuses on noise pollution. The app gathers noise levels data in the designated area, and the end-user experiences varying levels of audio and visual effects based on the level of noise pollution data. For example, when the noise level are low, the audio effects & music will be more relaxing, and the visuals will be colored in a light-blue hue. Higher levels of noise will introduce harsher audio and reddish colored visuals. The end-user is provided with information on potential health impact, related to the noise level scenario. Throughout the experience, the end-user interacts with a virtual companion named Julie, who provides helpful tips and serves as the narrator of the story. A dialogue system is utilized, along with speech and hand interactions, to create a sense of emotional attachment to the process of communication.

Figure 3: GoNature AR: Air Pollution Visualization

3.2 AR System Architecture

GoNature AR was developed for Hololens 2 in the Unity platform. The framework used to implement AR interaction is the MRTK framework based on OpenXR API. The processes of the system have been implemented into different subsystems:

Authentication Manager: This manager is responsible for authentication of the system. In order to request IoT data driving the visualization, the process has to be authorized using the OAuth2 protocol by acquiring an access token. Based on the access token, the application requests data requiring authorization using the VARCITIES REST API [24].

Data Query Manager: It sends REST API requests to the server, receives the responses form the server in JSON format, deserializes the data and makes them available to the data containers of the system.

Interactions Manager: It manages the input handlers provided by MRTK. Input handlers keep track of user's hands, head, gaze movements or speech commands recognition from a pre-defined vocabulary we implemented to fit the system's needs. It is also responsible for action completion related to event triggers of any input handler.

Audio Manager: It adjusts the volume of sounds and music. It enables specified audio effects related to event triggers and utilizes spatial audio allowing the creation of 3D audio sources in the scene; their volume signifying the distance of the user from the audio source and its direction signifying the orientation of the user in relation to the audio source.

Dialogue Manager: Throughout the whole experience, the user interacts and communicates with the companion using a dialogue system. Apart from speech recognition, the user can also hear the companion talk in the form of responses. The dialogue system has an appropriate response for each voice command. The voice overs of the companion were produced using Balabolka [1], a free test-to-speech (TTS) software that generated voice audios from text input. The companion responds both with voice and text in a chat box window.

Particles System: The particles and visual effects were implemented with the Visual Effect Graph (VFX) system within Unity. Unity's VFX Graph is a node-based visual effects editor suitable for creating complex particles. It uses a GPU-based simulation system to achieve high performance.

4 CONCLUSION

In conclusion, our innovative approach utilizing Extended Reality (XR) technologies, as demonstrated by the GoNature AR system, shows great potential for raising environmental awareness and promoting health and wellness. By seamlessly integrating sensor data, analytics, and multimodal inputs and outputs, GoNature AR goes beyond superficial visual overlays and provides citizens with real-time, interactive information on air and noise pollution. The system not only visualizes non-visible phenomena such as pollution particle concentrations and noise levels but also incorporates audio augmented reality (AAR) to enhance user engagement and immersion. By sensitizing citizen communities to the effects of air and noise pollution on human health and well-being, we aim to foster environmental consciousness and promote the positive impact of green spaces.

Looking ahead, future work will focus on enhancing the scalability of the AR system, ensuring wider deployment and adoption. This will involve improvements in gesture recognition, hands tracking, and voice command accuracy will optimize user interaction and usability. Further development of visualization techniques for air pollution and exploration of innovative representations for noise pollution will enhance the intuitive and informative nature of the AR experience. Additionally, extra visualization scenarios will be imported such as: biodiversity and temperature increase.

5 DEMONSTRATION

The proposed demo system involves the GoNature AR experience, and the scenarios based on the air & noise pollution phenomena. The visitors use a Hololens 2 device becoming aware of environmental conditions derived from data gathered from the VARCITIES network of sensors. The demonstration will take place on-site using the device. The experience has been designed mostly for outdoors

environments, but the overall feeling and experience will be adjusted to the specific place of operation at the conference. This process will provide valuable feedback and will serve as an evaluation exercise, helping us improve the overall experience.

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