Towards an Immersive WebXR-based Solution for Smart Farming: Enhancing Transparency and Comprehensibility in Agricultural Management

Irene Bouzón, Ignacio Pedrosa, Moisés Muñiz, Roberto Abad

Technological Center for Information and Communication (CTIC), W3C Spain Office host, Ada Byron 39, 33203 Gijón, Spain

irene.bouzon@fundacionctic.org (I. Bouzón), ignacio.pedrosa@fundacionctic.org (I. Pedrosa), moises.muniz@fundacionctic.org (M. Muñiz), roberto.abad@fundacionctic.org (R. Abad)

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Introduction

The rapid growth of Artificial Intelligence (AI) in recent times has seen an increasing adoption of machine learning techniques in various research areas. As a result, AI technologies have found their way into everyday life, impacting various user segments positively. Despite these advancements, the complexity of underlying algorithms poses challenges for end-users, especially those with limited digital proficiency, such as farmers. Consequently, transparency and comprehensibility issues arise, impeding human-computer interaction for end-users. This situation calls for innovative solutions that cater to user needs and enhance their understanding of AI-driven systems.

VR and AR hardware have witnessed significant growth in the consumer market, providing immersive computing experiences with new opportunities and challenges. Ensuring the seamless integration of the web in this environment is crucial for a first-class user experience. The WebXR Device API offers essential interfaces to developers, enabling them to build compelling, comfortable, and secure immersive applications across diverse hardware devices. This standard facilitates rendering 3D scenes in AR or VR, encompassing various web-connected devices, while effectively handling distinct user input controls and output display capabilities.

Furthermore, with the global population expected to increase substantially by 2050, agricultural production faces a tremendous surge in demand. Developing cost-effective and sustainable agricultural solutions becomes imperative, requiring a 90% intensification in technological farming to meet market demands while adhering to environmental and *twin transition* objectives. To address these challenges, an AI-based approach is needed to create a smart farming environment that offers real-time monitoring and management of agricultural issues.

This paper proposes an integral solution based on WebXR standards that aims to provide an immersive and trustworthy environment for farmers. Guided by a virtual agent, this solution seeks to offer real-time understandable information to farmers, empowering them to automate processes and make data-driven decisions to optimize production while adhering to sustainability standards. By fostering transparency and user-friendliness, this approach aims to bridge the gap between AI technologies and end-users, particularly in the agricultural sector.

Methods

To achieve the defined objectives, a digital twin of an agricultural scenario has been built and deployed as an immersive platform, compliant with WebXR standards in order to provide accessibility and ease of use. This digital twin graphically represents the agrarian landscape as a three-dimensional environment based on real world geographic data derived from satellite imagery, ensuring a high level of accuracy and authenticity in the virtual representation. The premises depicted in this area include a distinctive infrastructure such as a climate simulator that houses multiple terraces containing a variety of crops (i.e. faba beans, peppers, tomatoes, strawberries and red cabbage). This facility is equipped with several sets of sensors that provide real time information related to soil and ambient temperature, humidity and air quality, using a purpose-built IoT infrastructure based on LPWAN networks. These data can be monitored remotely within the proposed digital environment, which can be accessed through a web browser. Additionally, intelligent data analysis allows for early detection of abnormal events and activation of warnings and alerts.

A virtual agent has been embedded in this setting, playing the support role of a guide to provide information and facilitate the decision-making process. During the design of this virtual persona, socially relevant factors were taken into account, as well as the realism of these social attributes (i.e. social fidelity) to emulate natural, real-world interaction with the end user. Functional requirements were defined, a customized, XR-ready animated avatar was created, and an understandable content flow was developed with the help of two agri-food experts, so as to deliver an innovative and helpful experience. Wording has been carefully designed for clarity, simplicity and ease of understanding for any user not familiar with these sort of solutions.

To provide natural means of communication, this virtual agent is supported by Natural Language Processing technologies, such as Automatic Speech Recognition to allow the user to command by using their voice, and Natural Language Generation to produce a spoken response. This integration of voice capabilities establishes a dynamic and accessible communication flow for any user, regardless of their digital skill. In addition, the virtual agent is enhanced with lip sync to increase lifelikeness, along with several state-dependent animations that render the interaction more natural while providing feedback to the user, emulating non-verbal language (i.e. waving while welcoming the user).

The underlying conversational AI system that provides this agent with a “brain” operates as a chatbot with several stages. The system attempts to classify the user’s input with intent recognition in order to identify a question mapped to a predefined answer. When unsuccessful, it then generates extractive information out of the context the AI has been trained on.

Generative AI models were also tested, but their adoption for this use case was dismissed due to an excess of *hallucinations*, as well as producing a number of inappropriate responses, making it harder to reach the desired information.

Results

An IoT infrastructure based on LPWAN technologies has been deployed, along with the sensors required, designed to monitor key crop related variables in real time. This provides the whole area with a communications infrastructure suitable for a rural environment, which can be scaled up by adding new data sources over time.

The digital twin of the agrarian landscape of Peón (rural area in Villaviciosa, Spain) provides a friendly and accessible way to explore the territory and its features by means of a visual and engaging web application. It is also populated with several points of interest that depict and monitor the hyper-sensorized target facilities.

Figure 1. Landscape and target facilities digitization (left), virtual/real offices building comparison (right).

The CTIC RuralTech digital twin represents our research and development offices specialized in rural innovation and smart territories. This building is equipped with a home automation system that monitors and controls the state of its dependencies. This way, room presence, lighting and temperature data is integrated and spatially contextualized in the digital replica, providing an easy to understand, centralized interface that allows for operation from within (i.e. lights can be handled remotely).

Figure 2. Office digital twin, home automation data monitoring and manipulation.

The climate simulator digital twin is also seamlessly integrated into the digital landscape, likewise embedding soil and ambient temperature, humidity and CO2 data for remote monitoring. Critical levels for each of these parameters have been identified, so that real time warnings are triggered within the virtual environment in order to alert the user in case of anomalies.

Figure 3. Climate simulator digital twin exterior (left), crop data visualization (right).

The virtual agent is meant as an interface to ease the handling of the whole environment and guide the user within the application, providing comprehensibility and transparency. This character supports the user throughout the whole experience; being able to solve questions and provide detailed information by means of natural language, both spoken and written. Whether it is to unravel details about the area, the several points of interest, sensor data or general information about technologies involved, the character accompanies the user on an educational and immersive tour within this environment. Likewise, it can report any alerts detected to assist in troubleshooting, helping with their interpretation and notifying about critical events while also providing recommendations for corrective actions. This proactive approach allows users to understand the underlying logic of the warnings and to take informed actions accordingly, promoting active participation and greater control out of the virtual environment. A core feature of this agent is the embodiment of a well and dearly known local personality, Ramón Álvarez de Arriba, benefactor and donor to the region with many historical contributions to its development. By giving the character a friendly, approachable and recognizable appearance, connection and engagement with local agents is ensured, while social fidelity among users is increased.

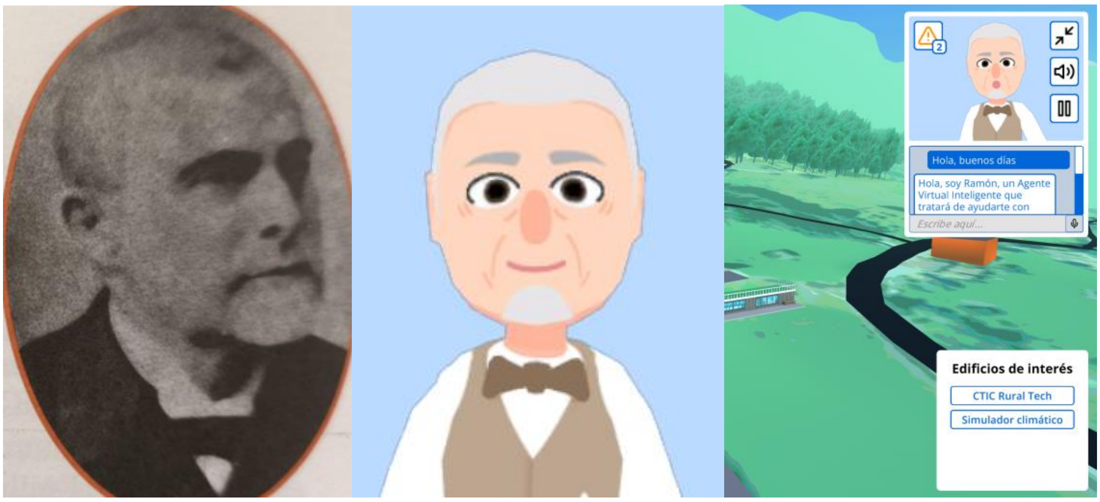

Figure 4. Ramón Álvarez de Arriba's picture (left), his embodiment as virtual agent (center), integration within the virtual environment application (right).

Lastly, the WebXR compliant deployment of the virtual environment allows for convenient availability using any kind of device or platform through the web, thus maximizing accessibility and allowing the solution to potentially reach any user, at any location. It empowers users, both those digitally proficient and newcomers, to seamlessly access and leverage the benefits of this immersive experience across a diverse range of contexts. WebXR integration extends to devices that allow for Virtual Reality capabilities, featuring an additional VR presentation and interaction mode, underlining this solution's adaptability and commitment to making the experience accessible to all. By delivering several presentation modes suited to the capabilities of multiple sorts of devices, an optimal experience can be ensured for every user.

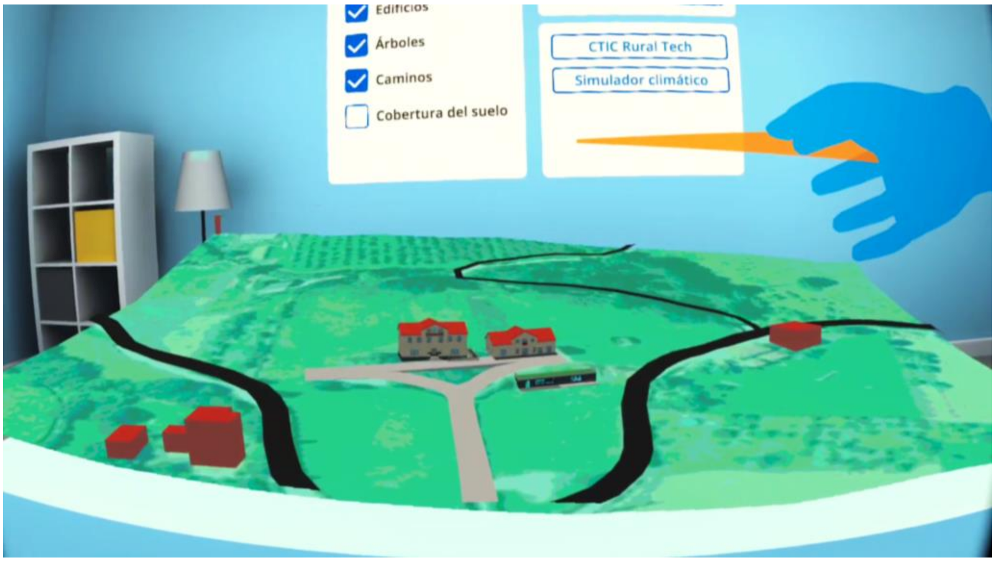

Figure 5. Virtual Reality WebXR visualization of the environment on Meta Quest 2 browser.

Conclusions

This paper presents a comprehensive solution that leverages WebXR standards to address the challenges faced by farmers in the context of AI-driven agricultural management. By integrating immersive technology and virtual agent guidance, this solution aims to promote trust, transparency, and comprehensibility, empowering farmers to embrace AI and enhance their agricultural practices under sustainability standards. This work contributes to the advancement of smart farming practices, benefiting both agricultural productivity and environmental stewardship.

Future Research Directions

Considering the focus of the present work, below are highlighted some relevant points, related to both user-centered design and technological development issues, as well as technical matters, to be taken into account when proceeding with future research.

Firstly, it would be interesting to assess the perceived level of social fidelity, aiming to align this aspect with user preferences and expectations, thereby enhancing trust, adoption, and use of such solutions. Active user engagement will be essential for this purpose.

In addition, it is relevant to evaluate the current level of technological acceptability of the final solution, especially concerning its transparency, in order to realize its inherent virtues and advantages.

Furthermore, given that the current solution relies on NLP, and considering recent developments in this field, exploring the use of Large Language Models linked with dialects existing in rural areas could be of interest to enhance usability and comprehensibility.

Lastly, a significant technical challenge towards promising research directions relates to the scalability and portability of this solution to other territories. Procedural generation of the terrain model based on GIS data will be considered in order to support dynamic regions of interest that display information from geolocated IoT sensors, ensuring that a solution as the one proposed could be applied elsewhere.

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