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Towards Unified Interface: Bridging Internet of Things and Augmented Reality

Prof. (Dr.) Sarvottam Dixit [1], Ushveen Kaur [2]

Department of Computer Science Engineering, Mewar University, India[1]

Department of Computer Applications, Mewar University, India[2]

Abstract: Augmented Reality (AR) and Mixed Reality (MR) provide users with immersive experiences where virtual elements blend seamlessly into the physical environment. However, to fully harness the potential of AR/MR devices, it is crucial to extend their capabilities by enabling interaction with physical objects connected through the Internet of Things (IoT). Achieving this integration is often hindered by the heterogeneity of underlying technologies, and typically demands the expertise of specialized developers to build the necessary communication mechanisms.

To overcome these challenges, this article presents a framework that simplifies the integration between AR/MR and IoT systems, enabling real-time and dynamic interaction. The proposed AR/MR-IoT framework relies on widely used open-source protocols and tools such as MQTT, HTTPS, and Node-RED. Following a detailed breakdown of the framework's architecture, its practical application is demonstrated through a use case involving the monitoring and control of a smart power socket using Microsoft HoloLens AR/MR glasses. Performance evaluation of this scenario shows that the framework consistently handles interaction and data update requests with response times under 100 milliseconds in typical operating conditions.

Keywords: IoT; Internet of Things; augmented reality; mixed reality; open-source framework; sensors; actuators

I. INTRODUCTION

The Internet of Things (IoT) concept has found applications in various domains, such as smart appliances, precision agriculture, smart healthcare, and urban development. Projections indicate a substantial growth in IoT deployments, with an estimated 75 billion devices operational by 2025. While many IoT systems are accessible through web-based or smartphone apps, recent advancements in Augmented Reality (AR) and Mixed Reality (MR) have the potential to revolutionize the way we interact with these systems.

Early developments in AR/MR date back to the 1960s, but their practical use on a large scale was limited. It wasn't until the 1990s, following Boeing's introduction of industrial AR applications, that AR/MR gained renewed attention from both industry and academia. A significant boost for AR/MR came in the late 1990s when the German government funded the ARVIKA project, involving major industrial players like Airbus, EADS, BMW, Audi, VW,Daimler, and Ford in the development of mobile AR/MR systems.

Fortunately, recent years have seen substantial improvements in AR/MR devices, thanks to advancements in electronics, computing, and wireless communication technologies. These developments have also led to a reduction in the commercialization cost of AR/MR devices, piquing the interest of new consumers and industries looking to transform their processes using Industrial IoT (IIoT) and Industry 4.0 paradigms.

II. PROBLEMS FACED BY AUGMENTED REALITY

One of the main challenges faced by AR/MR developers in interacting with IoT devices is the technology heterogeneity, which complicates even basic interactions. AR/MR frameworks often rely on technologies significantly different from those used in IoT device software development. Additionally, the skill sets required by AR/MR and IoT experts tend to differ, further complicating communication between these fields.

To enable AR/MR applications to interact with surrounding IoT devices, there's a need for communication mechanisms that facilitate data exchange in a common 'language' understood by all devices. However, developing such mechanisms is far from straightforward due to the aforementioned technology disparities, hardware limitations (especially for resource- constrained IoT devices), and the development constraints imposed by AR/MR frameworks.

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To address these challenges, this article makes several key contributions. It introduces an AR/MR-IoT framework designed to bridge the gap between AR/MR platforms and IoT devices using open-source standard communication protocols. This framework facilitates the creation of versatile and scalable applications while simplifying configuration and supporting the implementation of complex functionality. The article follows a hands-on approach, providing guidance and development examples through GitHub. Finally, the framework's performance is evaluated in terms of Quality of Experience (QoE), showing rapid interaction and data update responses in under 100 milliseconds under typical operational conditions.

The remainder of this article is structured as follows: Section 2 reviews related works, Section 3 details the design and implementation of the proposed AR/MR-IoT framework, Section 4 explains how the framework can be used to develop an energy monitoring and control application with a smart power socket and Microsoft HoloLens smart glasses, Section 5 evaluates the framework's response latency, and Section 6 provides the conclusions.

III. DESIGN OF THE UNIFIED SYSTEM

The primary objective of the proposed framework is to alleviate the complexities associated with interconnecting diverse systems, particularly those within IoT and AR/MR devices. To achieve this goal, the framework introduces a range of mechanisms and methods for linking various technologies through the use of standardized protocols. These protocols can be seamlessly integrated into the target platforms and existing projects. This section outlines the challenges encountered in the development of an AR/MR-IoT system, the system's requirements analysis, the design of each framework layer, and the approach to managing communication within each system component.

Creating an AR/MR-IoT framework involves addressing several often-overlooked challenges that necessitate consideration during the design phase. As previously mentioned, one of the foremost challenges is the technological heterogeneity required to construct a comprehensive AR/MR-IoT system. This challenge involves making critical low-level decisions concerning architecture and software within diverse domains of knowledge.

Latency stands as another significant challenge. To ensure a satisfactory user experience, maintaining low response times for various communication protocols, component interactions, and processing tasks is imperative. If any part of the system introduces delays in the flow of information, it can become a bottleneck, ultimately impairing the system's usability.

Both AR/MR and IoT systems are inherently complex, making the integration of a new communication architecture into existing software a formidable task. Therefore, the technologies employed by an AR/MR-IoT framework for facilitating diverse interactions must be easily interactable into preexisting projects. This can be achieved through the provision of well-documented open-source software.

While some of the prior works mentioned in Section 2 have addressed specific challenges outlined here, none were found in the literature that comprehensively tackled all of them. Thus, Table 1 compares the features of the proposed framework with those of the three most closely related previous works.

Table 1. Comparison of the challenges addressed by the most relevant AR/MR-IoT frameworks.

Work	IoT Device Heterogeneity Support	AR/MR Device Heterogeneity Support	Open Source	Latency
Seungwoon Lee et al. [29]	Yes (OneM2M)	Yes (HTTP)	No	No assessed
ARIoT [28]	Not specified	Not specified	No	Not assessed
VEoT [31]	Yes (HTTP)	Yes (HTTP)	No	Not assessed
Proposed Framework	Yes (MQTT)	Yes (HTTP)	Yes	<100 ms

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IV. COMPONENT MODEL

Figure 1 displays the system's component model, providing a visual representation of the primary inputs, outputs, and processing elements within the AR/MR framework. This serves as a foundation for future research endeavors. In terms of inputs, a variety of data sources are integrated, generating information subsequently utilized by the processing components. These data sources encompass:

Surrounding IoT devices: These devices serve as data sources, providing information about their sensors and internal states.

- AR/MR device sensors: Embedded sensors in AR/MR devices collect data that helps in detecting the user's current location, previous locations, the user's line of sight, and their posture.
- User profile: The framework can utilize user-specific information to determine permissible actions and accessible information. For instance, in a smart home setting, restrictions may be imposed on actions that children can perform on certain appliances. Additionally, the user profile can be linked to past actions, using them as contextual information for future actions. This can enable the framework to infer user habits from their previous actions, preparing frequently used IoT devices in advance, thereby reducing interaction latency and energy consumption.

External inputs: Certain external inputs, originating from remote users or external services (e.g., Network Time Protocol or weather forecast services), can impact the timing and manner in which actions are carried out on IoT or AR/MR devices. For example, an AR/MR user's interactions with an IoT device may differ based on whether they occur during the day or night.

- System configuration parameters: System administrators have the authority to define specific rules and thresholds that govern how AR/MR user interactions are executed on IoT devices.

Ultimately, concerning the depicted results in Figure 1, they pertain to the engagement with nearby IoT devices. This encompasses the capability to take action upon them or retrieve specific information from them. Additionally, these outputs are relevant to the interaction with AR/MR devices, facilitating tasks such as displaying specific content or storing particular data in the memory of the AR/MR device for subsequent use.

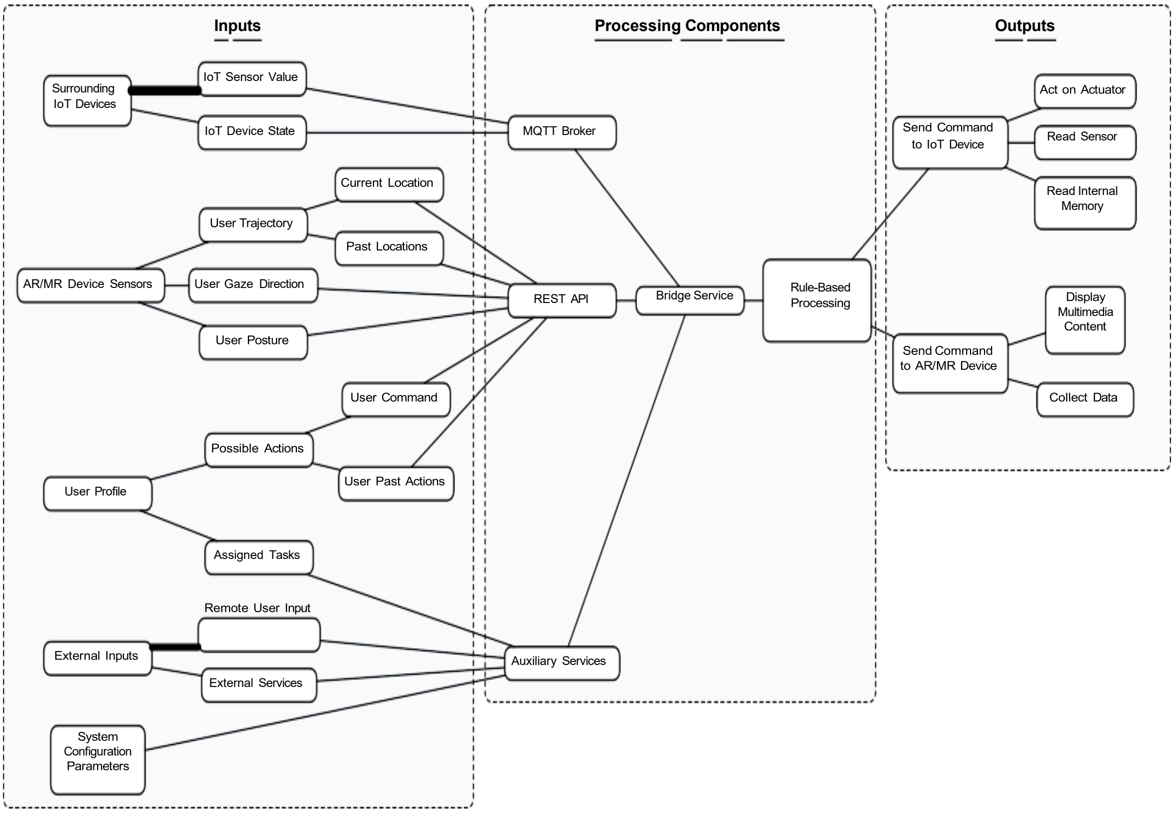

Figure 1 Component model of the proposed framework.

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V. CONCLUSION

This article introduced an AR/MR-IoT framework designed to simplify the integration of AR/MR and IoT devices. The framework leverages established open-source protocols and tools, facilitating dynamic real-time communication between AR/MR and IoT devices. After reviewing the current state of the field, this paper detailed the framework's design and implementation, offering comprehensive insights into its application in a real-world scenario: an AR/MR-controlled energy monitoring system using a smart power outlet and Microsoft HoloLens. To assess the framework's performance under varying computational loads, experiments were conducted.

VI. FUTURE SCOPE

The results demonstrate that, under typical operational conditions, the framework can respond to interaction and data update requests in less than 100 milliseconds. However, for workloads exceeding 50 requests per second, Node-RED operations introduce a latency bottleneck. Addressing this bottleneck would require optimizing data access for faster performance.

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