Mixed Reality-Enabled Multilateral Collaboration Application Platform with AI and IoT Convergence

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***Abstract*—Internet of Things (IoT), Artificial Intelligence (AI), and Mixed Reality (MR) are recognized as ones of the most promising core technologies to lead the 4th industrial revolution. Converging MR with IoT and AI helps recognize situations by displaying the contents of analyzed data obtained from IoT servers on HMD. In this paper, we introduce the MR-enabled Convergence Platform with AI and IoT, called MR-IoT/AI Convergence Platform, shortly MIAcP, and MR-enabled multilateral collaboration application platform as an example of MIAcP. Then, we present the use cases of the applications that can apply to various fields such as disaster response, military surveillance, industrial digital twins, themed entertainments, and others.**

***Index Terms*—Mixed Reality(MR), Internet of Things (IoT), Artificial Intelligence (AI), Convergence Platform, Disaster Response, Military Surveillance, Digital Twin**

I. Introduction

Internet of Things (IoT), Artificial Intelligence (AI), and Mixed Reality (MR) are recognized as ones of the most promising core technologies to lead the 4th industrial revolution. Each technology makes it possible to create many application services independent of others. Among those, MR is the most effective means for complex information expression, and it is possible to provide an immersive user experience to express hologram information in the physical location of objects. Also, MR provides freedom of hands by utilizing Head Mounted Display (HMD) devices. Accordingly, when IoT and AI are fused with MR, much higher value-added services can be created [1]. Converging MR with IoT and AI helps recognize siutaions by displaying the contents of analyzed data obtained from IoT servers on HMD. At the same time, it is possible to use free hands to operate devices or objects, perform various necessary actions, and others. However, converging the technologies with heterogeneous technical characteristics and service structures is very challenging [2].

There have been some works to provide services or applications by converging the technologies. In [3], the works done for the convergence of Augmented Reality (AR) and IoT is summarized. In [4] and [5], architectures and frameworks for the convergence of IoT, AI and MR. In [6], the applications areas with the convergence of these technologies and the issues extending it to Metaverse are presented.

This paper introduces the methodologies and architectures to develop an application platform converging MR, AI, and IoT technologies, called MR-IoT/AI Convergence Platform, shortly MIAcP. Then, as an example solution using MIAcP, we present a multilateral conference application platform that combines IoT, AI, and MR technologies. The solution enables individually developed application and service components to be interconnected in the common development environment. It can also be a kind of platform extended to other application fields. We present the use cases of the solution as a platform that can apply to various fields such as disaster response, military surveillance, digital twin, themed entertainment, and others.

II. Design and Implementation of Multilateral Collaboration Service Platform with MIAcP

A. MIAcP: MR-enabled convergence Platform with IoT and AI

To merge IoT and MR services working on common environment, oneM2M-based convergence platform architecture has been developed [2]. oneM2M is the global standards initiative that specifies requirements, architecture, application program interfaces (APIs), securities, and interoperabilities for Machine-to-Machine (M2M) and IoT technologies. By having MR devices follow entities and interfaces specified in oneM2M standards, information between MR and IoT systems and services can be exchanged without any gateway systems that converting their data. Authors of [2] have developed the MR-IoT convergence platform using the open-sourced platforms by OCEAN Mobius, certificated by oneM2M [7]. It is suitable for developing MR-enabled application services directly linked to IoT. However, it is limited in providing a high-level convergence of MR and IoT with other application systems or services which have not complied with oneM2M standards.

To overcome the limitation, we design an MR-enabled Convergence Platform with AI and IoT (MIAcP) based on microservice architecture (MSA) as shown in Fig. 1. oneM2M-based IoT platform is considered as a unit MSA in MIAcP.

MIAcP is mainly constructed with three layers: infrastructure, user, and field, as shown in Fig. 1. The infrastructure layer consists of microservices running in the cloud or edge. Infrastructure services primarily include IoT and AI services that combine one or more microservices. Each microservice includes communication components such as external APIs, API clients, and messaging clients. IoT services include communication APIs, and AI services provide APIs for intelligent situation recognition and decision support. Each service has an API gateway for communication with users and services. It has a distributed architecture over messaging channels for communications. The user layer supports several clients and apps. The field layer includes various devices, including IoT sensors and actuators.

Each MR device interworks with MIAcP through Application Programming Interface for MR (MRAPI), which provides access to three fields, as shown in Fig. 1. MRAPIs provide interfaces to exchange data between MR device and all microservices at three layers of MIAcP. The primary role of an MR device is to run client applications with immersive and intuitive dashboards for intelligently monitoring and controlling IoT-enabled devices participating in MIAcP.

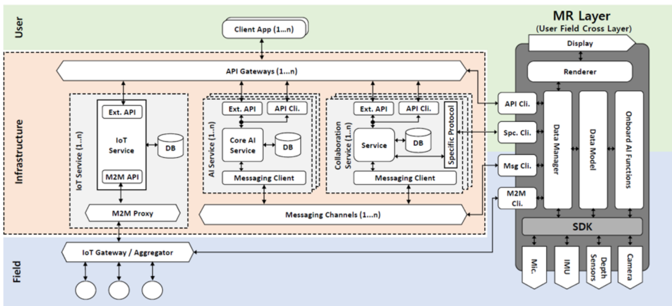

Fig. 1. Microservice architecture-based MR-IoT/AI convergence Platform (MIAcP) architecture

B. MMCA platform: MR-enabled Multilateral Collaboration Application Platform with MIAcP

MIAcP enables the development of various application services with MR devices. It recognizes target objects by analyzing the image captured from MR devices with AI services, finds information related to the objects from IoT service, and augments the fused context on HMD in real-time. In addition, it supports decisions that can respond to certain situations by recognizing and predicting environmental changes in real-time. It then performs the responsive actions using MR device interfaces incorporated with IoT systems.

As an application using MIAcP, we developed a prototype of an immersive multilateral collaboration service between the central control center (CCC), field workers, and external experts, as shown in Fig. 2.

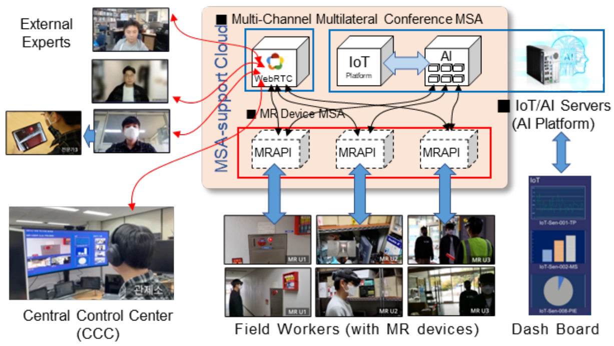

Fig. 2. Prototype implementation of MMCA platform using MIAcP

As an MR device, Microsoft's HoloLens is used. The MR device platform, IoT platform, and AI service are configured in microservices to support the analysis of MR images incorporating IoT data, object recognition, and situational awareness in real-time. It provides an immersive multi-channel multi-party conference function between CCC commanders, field workers wearing MR devices, experts who access using mobile devices or PCs, and rescuers. In addition, precise drawing for matched objects on MR display for accomplishing missions to workers, immersive content and visualization to respond to situations effectively are provided. This MIAcP-based immersive collaboration solution is expected to apply to all industrial and military fields that require the fusion of MR, IoT, and AI applications. Fig. 3 shows example functions implemented in the MMCA platform such as the on-site manual display, video conferencing on MR display, and expert's drawing and its position and time synchronization on the MR screen.

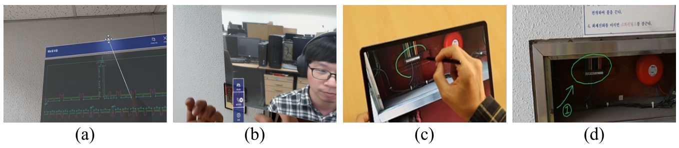

Fig. 3. Some applications implemented on MMCA platform: (a) on-site manual, (b) MR conferencing, (c) remote expert's drawing, and (d) drawing synchronization on MR device

III. Use Case Study of MR-IoT/AI Convergence Platform

A. Disaster and Safety Response

One of the most applicable areas that can utilize MIAcPs is disaster and safety. In disaster and safety, for example, damage to property, resources, and human lives can be considerable in large-scale fire cases. Rapid collaborations and responses between various members for the on-site response, central control, and other participants, including experts and rescuees, should be done to minimize the damages. Since MR devices provide the freedom of hands while visually observing the situation, it is possible to effectively perform the necessary hand operations while watching the case in the field so that it is possible to respond very effectively to the disaster situation. From this point of view, the MMCA platform described in Section II-B can provide a very effective solution that can respond to disasters and safety situations.

Fig. 4 shows a conceptual example architecture of a situation where the MMCA platform is applied to respond to disaster and safety situations. Information acquired by CCTV, drones, and various sensors that provide field information is sent to and stored in IoT servers. AI servers analyze the data and provide the decision support information individually necessary to the control tower, on-site rescue team, experts, and others. Multilateral conference service is utilized between them to guide and decide actions effectively responding to the case. When the location-based service (LBS) is added as a microservice component, as in [1], additional services can be provided that track the location of situations or guide possible routes to avoid or respond to the situations.

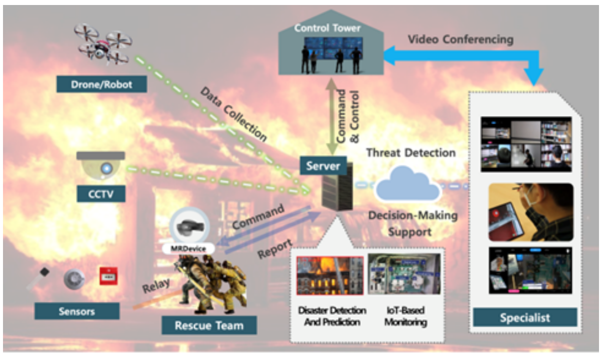

Fig. 4. Conceptual usage diagram of MMCA platform for disaster response

B. Military Surveillance and Reconnaissance

Traditionally, soldiers on battlefields had performed surveillance tasks using naked eyes and telescopes with night vision. Now, the situation awareness (SA) capabilities can be increased with Augmented Reality (AR) technologies between soldiers and command post (CP) agents in battle spaces [8]. MR technologies can provide interactions between humans and real or virtual objects. In military fields, it can be utilized for task training of military weapons, systems, or others via MR-based simulators and command & control for operations or surveillance, in which various tools such as displays, sensors, cameras from the ground and drones, and others [9].

The MMCA platform can improve SA and operational capabilities through surveillance and reconnaissance and provide the ability to respond to situations. Fig. 5 shows an example mapping of components for military surveillance and reconnaissance applications to MMCA platform. MMCA platform shown in Fig. 2 can be divided into essential components of IoT, AI, and MR platforms and WebRTC for multilateral conferences.

Data sources such as sensors, CCTVs, drones, and so on are involved with IoT platforms and stored in databases (DBs). Also, image, video, and sound data at fields are generated from HMDs worn by soldiers or vehicles, which correspond to filed workers in the basic MMCA platform architecture. AI platforms provide information supporting decision-making by analyzing data stored at DBs. With the information, responses to certain situations between soldiers and LCC agents can be made. It can also communicate with remote experts and high-level CCC for collaborative surveillance and response. For naval environments, communication may be accomplished via satellite. Soldiers, as field workers, can view the site and relevant information simultaneously on HMD. With the freedom of hands, they can effectively access and control the situations with coping and guidance from CCC and experts.

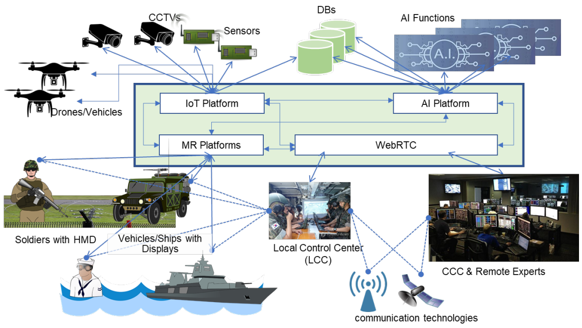

Fig. 5. Example usage of MMCA plaform for military surveillance and reconnaissance

C. Industrial Digital Twin

MIAcP can make it easier for workers to understand manufacturing situations and help them make better decisions and activities about the tasks they need to perform. An AR/VR-assisted service system for smart factories has been proposed in [10]. It helps to effectively perform the task by detecting objects to be completed in the workplace through AR, displaying a VR image synchronized with the actual objects, and providing live manuals. By connecting with CCC as in MMCA platform, as shown in Fig. 2, the service can be more effective to collaborate among several distributed on-site workers under guidance by CCC or remote experts.

Authors in [11] presented MR's application potentials in production and logistics, including assembly, system monitoring, maintenance, quality management, logistics, and robotics. The applications are closely related to industrial digital twins. They also presented detailed tasks to fulfill the applications, such as telepresence, learning, control and steering, visualization, environments, and assistant systems. The paper considered focusing on MR with HoloLens devices. Combining IoT and AI with MR applications can achieve better effects in the fields of industrial digital twins.

D. Live Control and Themed Entertainment Areas (TEA)

MIAcP allows systems to be interoperable and extends its capacity to the area of themed entertainment (TEA) in which multiple systems work together to create a simulated thematical augmented environment such as amusement parks and themed live entertainment. As shown in Fig. 6, the nature of TEA deals with real-time data that includes motion, audio, video, and other operation-related information – monitoring power signals, communications, safety-related protocols, etc. The proposed MIAcP will be crucial in integrating these multi-aspects of real-time information and presenting it on a wearable display or multiple displays in a stationary control center. This would facilitate advancing various types of applications in the TEA industry. The reason for this is that MIAcP would provide more integrated systems control cues as well as organized monitoring status and thus would facilitate the advancement of the TEA industries.

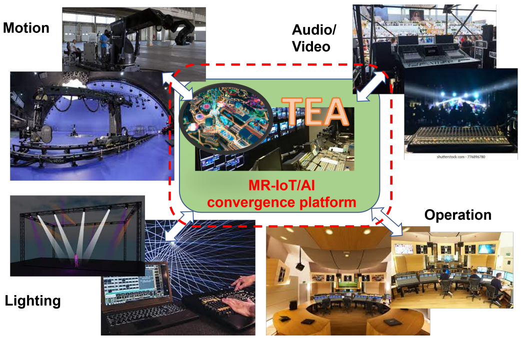

Fig. 6. A Conceptual Diagram of MR-IoT/AI Platform in TEA

E. Others

When it needs to develop applications with multilateral cooperation requiring immediate responses and communications through the continuous acquisition of various information that occurs simultaneously and analyzing them in real-time, the MIAcP will be commendable. In this context, MIAcP will perform as a central module that acquits data through IoT units and organize and presents the data to users as multimodal feedback. MIAcP would facilitate collaborations with other disciplines, such as human-computer interactions, data science, and information architecture.

Integrating drones and IoT can be utilized in various applications and services. Authors in [12] proposed a platform architecture combines oneM2M standard and drone systems to support these use cases effectively. Since this architecture can be easily adopted in the MIAcP structure shown in Fig. 1, the combined services with drones and MIAcP will be expected to be applied to various application fields.

IV. Conclusion

In the paper, we introduced the MR-enabled Convergence Platform with AI and IoT, called MR-IoT/AI Convergence Platform, referred to as MIAcP. MR and IoT support systems and services incorporated with AI are interlinked on a single platform. As an example of applications using MIAcP, an MR-enabled multilateral collaboration application (MMCA) has been developed. We have presented five representative use cases where MMCA can be utilized and applied to various fields. Since MMCA can be utilized in different application areas, it can be considered another platform to be extended and applied in other fields in addition to those listed in this paper.

Extending the current work, multidimensional development is being promoted for various services and expansion applications, such as disaster response, military surveillance, and industrial digital twins, using the results of this study.

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References

[1] G. Choi, S. Lee, B. Roh, J. Kang, and S. Kim, "A Design of Safety and Disaster Response System with XR, IoT and LBS Convergence," in *2019 International Conference on Computational Science and Computational Intelligence (CSCI)*, Las Vegas, NV, USA, Dec. 2019.

[2] S. Lee, W. Kil, B. Roh, S. Kim, and J. Kang, "Novel Architecture of OneM2M-Based Convergence Platform for Mixed Reality and IoT," *Computers, Materials & Continua*, vol. 71, no. 1, pp. 51–69, Jan. 2022.

[3] N. Norouzi, G. Bruder, B. Belna, S. Mutter, D. Turgut, and G. Welch, "A Systematic Review of the Convergence of Augmented Reality, Intelligent Virtual Agents, and the Internet of Things," in *Artificial Intelligence in IoT*, F. Al-Turjman, Ed. Cham: Springer International Publishing, Feb. 2019, pp. 1–24.

[4] A. Morris, J. Guan, and A. Azhar, "An XRI Mixed-Reality Internet-of-Things Architectural Framework Toward Immersive and Adaptive Smart Environments," in *2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, Oct. 2021.

[5] S. Kim, S. Lee, and B. Roh, "Microservice-Oriented Platform Architecture for the Convergence of IoT, MR and AI Mixed Applications," in *The 7th International Conference on Next Generation Computing (ICNGC) 2021*, Jeju Island, Korea, Nov. 2021.

[6] K. Li, Y. Cui, W. Li, T. Lv, X. Yuan, S. Li, W. Ni, M. Simsek, and F. Dressler, "When Internet of Things meets Metaverse: Convergence of Physical and Cyber Worlds," *arXiv*, Aug. 2022. [Online]. Available: https://doi.org/10.48550/arxiv.2208.13501

[7] IoTKETI/Mobius. oneM2M IoT Server Platform. [Online]. Available: https://github.com/IoTKETI/Mobius

[8] M. Chmielewski and K. Sapiejewski, "Augmented reality mechanisms in mobile decision support systems supporting combat forces and terrain calculations-a case study."

[9] R. J. Stone, "Blending the best of the real with the best of the virtual: Mixed reality case studies in healthcare and defence," in *Augmented Reality and Virtual Reality: Empowering Human, Place and Business*, T. Jung and M. C. tom Dieck, Eds. Cham: Springer International Publishing, Sep. 2018, pp. 277–293.

[10] M. Kim, K. Park, S. Choi, J. Lee, and D. Kim, "AR/VR-based live manual for user-centric smart factory services," in *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0*, I. Moon, G. M. Lee, J. Park, D. Kiritsis, and G. von Cieminski, Eds. Cham: Springer International Publishing, Aug. 2018, p. 417–421.

[11] S. Lang, M. S. S. Dastagir Kota, D. Weigert, and F. Behrendt, "Mixed reality in production and logistics: Discussing the application potentials of Microsoft HoloLens^{TM}," *Procedia Computer Science*, vol. 149, pp. 118–129, 2019, iCTE in Transportation and Logistics 2018 (ICTE 2018).

[12] S. Lee, B. Roh, and S. Kim, "The convergence system of an IoT standard service platform and an autonomous drone," in *IEEE ICCE 2022*, Las Vegas, NV, USA, Jan. 2022.