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Design Strategies of Multiplayer-Synchronized AR Interactive Entertainment Products for Open Space

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Abstract. Augmented Reality (AR) for interactive entertainment is exploring the potential of open space and multiplayer synchronization to expand user experience on mobile devices. However, complex interaction problems have hindered the development of related products. Based on a hybrid research methodology, this study proposes a set of design strategies including design elements, design framework, and functional attributes with priority ranking. To verify the effectiveness of the strategies, we developed ParallelWorld as an application example. It incorporates three basic modes of multiplayer-synchronized AR interaction: player to player, multiplayer to one virtual element, and multiplayer to physical space. Usability test and user interview suggest that ParallelWorld delivers a qualified experience for synchronized multiplayer in open space.

Keywords. Augmented Reality, Interactive Entertainment, Open Space, Multiplayer Synchronization, Mobile Application Design Method

1. Introduction

With the power of digital technology, modern society is accelerating to construct the digital civilization and virtual world. Augmented Reality (AR) is one of the most direct and effective technologies to promote the integration of virtuality and reality. It superimposes virtual information on the physical environment, and aims to reinforce the user's perception of and interaction with the real world. In terms of application, interactive entertainment provides a broad and active arena for AR. The feeling of immersion brought by AR enhances the fun and social experience in entertainment. Rather than traditional indoor usage scenarios, some AR games such as Pokémon Go and Ingress target open space. Such products not only hit the global game market, but also started a trend of open-space-oriented AR entertainment.

Meanwhile, more and more AR entertainment products integrate multiplayer synchronization in their interaction design (Bhattacharyya et al. 2019; López-Faican and Jaen 2020; Masneri et al. 2022). Multiplayer synchronization is a type of interaction as opposed to multiplayer asynchronization. In multiplayer-synchronized AR (MSynAR), users enter the same virtual environment and interact in real time; their actions and

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movements are synchronized to each other's view. Multiplayer synchronization improves the level of collaboration and the social experience, which is demonstrated in MMO (Massively Multiplayer Online) games (Raith et al. 2021).

The intersection of open space and multiplayer-synchronized interaction is not an accident but conforms to the development trend of AR entertainment. Scholars identified the trend as early as 2008: from small-scale personal entertainment to large-scale and event-driven one in physical environments (Broll et al. 2008). However, universal theoretical research for MSynAR interactive entertainment products for open space (MSynAR-IEPOS) is still in lack. Macroscopically, the product is in the exploratory stage with relatively few product cases. As for micro factors, the design work is subject to a series of unresolved design problems. Therefore, a thorough study of MSynAR-IEPOS's design strategy has great research and practical value.

2. Background

2.1. AR for Open Space

AR for open space gradually gains popularity among researchers and product developers. In 2011, the concept of AR 2.0 emerged, which highlights the application of AR in open space (Schmalstieg, Langlotz and Billinghurst 2011). AR 2.0 advocates shifting the majority of AR content creation from researchers and product developers to ordinary users. By providing pervasive location-based AR experiences based on UGC (User Generated Content), the core is to enhance creativity, collaboration, sociability, and information sharing. Nevertheless, AR for open space is not purely location-based services (Liu 2020) but requires a comprehensive perception of the user's environment and provides more personalized services. What really introduces it into the public horizons is a series of commercialized AR entertainment products launched by Niantic. The most famous product is Pokémon Go. It utilizes the camera and GPS on the smartphone to create AR environments. Players walk around and explore the surroundings to catch virtual fairies. Open space expands the activity space and adds uncertainty to user experience and system management.

2.2. Multiplayer-Synchronized Interaction in AR

Multiplayer synchronization facilitates collaboration and improves the user's social experience (Raith et al. 2021), as does AR. Billinghurst confirmed AR's potential for promoting collaboration and highlighted the advantages of collaboration with AR (Billinghurst and Kato 2002). The fusion of multiplayer-synchronized interaction and AR (MSynAR) can contribute to a better collaborative atmosphere in virtual settings.

The key point in identifying MSynAR is twofold: (1) the synchronization of information exchange under the conscious control of message senders and receivers; (2) the user's ability to proactively access other people's actions and movements in real time, even if the message senders do not intend to provide the messages. Mainstream AR products, like Pokémon Go, only support single-player experience, or multiplayer-synchronized interaction with restrictions. In the strict sense, the latter is not synchronization because it fails to satisfy the second requirement of MSynAR. It simplifies the multiplayer problem into multiple single-player problems to achieve effects similar to multiplayer synchronization. MSynAR products satisfying the two requirements have emerged in recent years (Bhattacharyya et al. 2019; Guo et al. 2019; Abbs et al. 2022), due to advancements in instant communication and 3D registration

technology. Each participant has easy access to others' actions and movements without their conscious cooperation. Nonetheless, existing MSynAR products are primarily geared towards two-player and indoor scenarios. Open scenarios with more users and larger spatial scales require further research.

2.3. MSynAR for Open Space

MSynAR-IEPOS is an AR entertainment product for multiplayer-synchronized interaction in open space. It is generally arranged on mobile devices and based on three technical modules: AR rendering, positioning and tracking, and instant communication. AR rendering module projects the virtual 3D model into the AR scenes. Positioning and tracking module acquires the user's position and movement, and continuously tracks or predicts the moving trajectory. It assists the rendering module in displaying virtual content in the appropriate position and orientation. Instant communication module synchronizes one's movements, location, voice, and other information across all users' visual fields in real time, thus finally enabling multiplayer collaboration.

AR for open space and multiplayer-synchronized interaction are two fundamental components of MSynAR-IEPOS. They distinguish the product from traditional desktop AR. Based on the two components, the interaction experience of MSynAR-IEPOS has the following features (Table 1): sharedness, concurrency, seamlessness, sociality, dynamicity, and space integration. It not only enhances interactive experiences in virtual settings, but also promotes physical fitness.

The design of MSynAR-IEPOS faces complex challenges. Technical challenges involve the communication module's network latency and data loss, and the positioning and tracking module's lack of immediacy, accuracy, and robustness. Excluding technical factors, there are six problems with interaction and experience design (Table 2): interactive message confusion, social experience problem, dynamic interaction problem, experience scale problem, and security risk problem. These six problems are intertwined and call for holistic solutions.

Table 1: Interaction features for MSynAR-IEPOS.

Interaction Feature	Description
Sharedness	Multiple users share the same virtual scene, and maintain a consistent perception of the scene.
Concurrency	A virtual scene may be affected by interactions from multiple users at the same time. Also, interactions from different users may overlap and affect each other.
Seamlessness	There are seamless interactions between virtuality and reality (Billinghurst and Kato 2002). User's interaction with the virtual world is also the exploration of the real world, and triggers other user's perception and feedback in real time.
Sociality	Users interact with each other in real time. Both competitive and collaborative AR games improve participants' mood and increase their engagement in group activities (López-Faican and Jaen 2020).
Dynamicity	MSynAR-IEPOS grants users much freedom of movement and encourages outdoor sports (Khamzina et al. 2020). During user's movement, virtual content also needs adjustment in real time.
Space integration	AR's embedding into large-scale scenes such as cities and parks implies a large-scale integration of virtual and real space. This space integration comes with an increase in physical risks, such as traffic accidents (Rauschnabel, Rossmann and Dieck 2017).

Table 2: Design problems for MSynAR-IEPOS.

Design Problem	Problem Description
Interactive message confusion	The huge amount of information from different users, virtual or real, may cause confusion in users' cognitive and behavioral order. For example, it is difficult for other users to identify the initiator of an interaction event, and users and passers-by are easily confused.
Social experience problem	Static virtual elements in AR can hinder eye contact between users to some extent, thus reducing their social experience (Miller et al. 2019). The issue of how to rationally design virtual elements and dynamic interaction mechanisms to improve user engagement and social experience needs to be focused on.
Dynamic interaction problem	Mobile-based entertainment usually involves physical activity (Mueller et al. 2020). Accordingly, the design must consider factors such as uncertainty of the route, social distance and physical contact.
Experience scale problem	Open space imposes higher requirements on the accuracy and stability of the positioning and tracking technology. Meanwhile, the presence of virtual objects may interfere with the user's judgment of spatial distance, resulting in spatial perception bias (Keil et al. 2020).
Environmental adaptation problem	AR products have to overcome the uncertainty and complexity of open space, optimize the contextual relationship between virtual elements and real environments, and ensure the continuity of attributes such as location, appearance, and behavior.
Security risk problem	Virtual elements may distract the user or obscure the real field of view, leading to neglect over road traffic and other potential hazards (Jung et al. 2018; Aromaa et al. 2020).

3. Design Strategies of MSynAR-IEPOS

This section focuses on the design strategies of MSynAR-IEPOS. To build a clear and unified background, we set the product target users as teenagers and young adults aged 14-28, and the application scenario as public open space. The main goal is to solve the six design problems (Table 2) and realize qualified user experience.

3.1. Design Elements and Framework

Design elements are key components of design strategies. Although there are no mature theories that directly address the user experience factors in MSynAR-IEPOS, relevant theoretical frameworks include the motivation of virtual community users (Dholakia, Bagozzi and Pearo 2004; Wang and Fesenmaier 2004), game design elements (IJsselsteijn, De Kort and Poels 2013; Macklin and Sharp 2016; Chou 2019), and AR product experience elements (Rauschnabel, Rossmann and Dieck 2017; Wei 2020). Combining the theoretical frameworks, product features, and design problems mentioned above, seven design elements of MSynAR-IEPOS are refined (Table 3): sensory experience, feeling of immersion, gameplay mechanics, value and competency, social experience, physical activity, and personal security.

According to the mapping relationship of interaction between subject and object, we outline three basic modes of MSynAR interaction (Figure 1): player to player, multiplayer to one virtual element, and multiplayer to physical space. Further, we divided the design framework into three layers: the virtual layer, the physical layer, and the social layer. This division corresponds to the AR and social attributes of MSynAR-IEPOS. The final framework (Figure 2) visualizes the design elements and their relationships,

information flow, and interaction modes. It is expected to provide a systematic perspective and theoretical support for MSynAR-IEPOS design.

Table 3: Design elements for MSynAR-IEPOS.

Design Element	Source
Sensory experience	IJsselsteijn, De Kort and Poels 2013; Rauschnabel, Rossmann and Dieck 2017; Wang and Fesenmaier 2004
Feeling of immersion	IJsselsteijn, De Kort and Poels 2013; Rauschnabel, Rossmann and Dieck 2017; Macklin and Sharp 2016
Gameplay mechanics	IJsselsteijn, De Kort and Poels 2013; Chou 2019; Rauschnabel, Rossmann and Dieck 2017; Macklin and Sharp 2016
Value and competency	IJsselsteijn, De Kort and Poels 2013; Chou 2019; Rauschnabel, Rossmann and Dieck 2017; Macklin and Sharp 2016
Social experience	Dholakia, Bagozzi and Pearo 2004; Chou 2019; Wang and Fesenmaier 2004; Wei 2020
Physical activity	Rauschnabel, Rossmann and Dieck 2017; Wei 2020
Personal security	Rauschnabel, Rossmann and Dieck 2017; Wei 2020

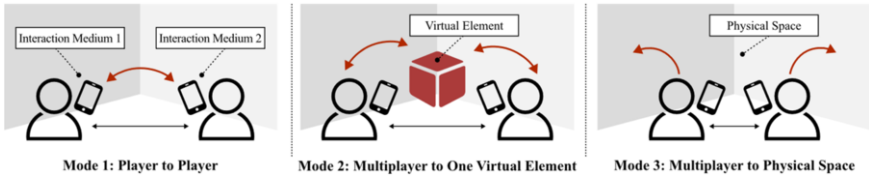

Figure 1. Three basic modes of MSynAR interaction.

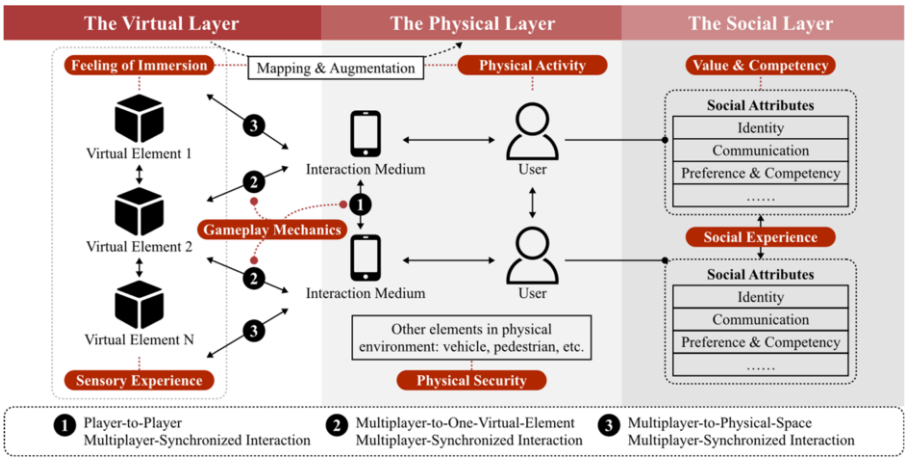

Figure 2. Design framework for MSynAR-IEPOS.

3.2. Functional Attributes with Priority Ranking

In order to connect the abstract design framework with concrete design practices, this section focuses on MSynAR-IEPOS's functional attributes.

Focus interview is a widely used qualitative method to gain insights into participants' ideas, understandings, or suggestions through group discussions. It helps researchers to comprehend the user's perspective and rationally design the functional attributes. We convened six potential target users, including two with only a basic understanding of AR products, two senior practitioners and two in-depth users of AR entertainment products. The participants have equal numbers of males and females with an average age of 26.3 years. The interview process is as follows:

- Step 1. Researchers introduced participants to the purpose, background, and procedure of the focus interview.
- Step 2. Researchers introduced the design elements and framework of MSynAR-IEPOS. Participants brainstormed specific functional attributes around each design element. Once one put forward a view, others made comments and inquiries.
- Step 3. Participants had a free discussion about MSynAR-IEPOS's functional attributes.

After refining and coding the interview transcripts, we got 29 functional attributes (Table 4). We formulated a questionnaire based on the KANO model (Sharif Ullah and Tamaki 2011) to assign different priorities to the attributes. We received 60 valid responses from 38 males and 22 females with an average age of 23.2 years. KANO analysis shows that among the 29 attributes, there are 6 excitement functions, 4 satisfaction functions, 8 must-be functions, 11 indifferent functions, and no dissatisfaction functions (Figure 3). Moreover, attributes within the same hierarchy in Figure 3 are ranked in order of decreasing importance from left to right and top to bottom. Product design should ensure the must-be functions before pursuing the satisfaction and excitement functions.

Table 4: Coding results for the functional attributes of MSynAR-IEPOS.

Design Element	Serial Number	Functional Attribute	Design Element	Serial Number	Functional Attribute
Sensory experience	SE1	Attractive virtual protagonists and NPCs	Gameplay mechanics	GM5	Distance-dependent interaction triggers
	SE2	Intrinsic interaction among virtual elements		GM6	Intuitive interaction interface
	SE3	Endearing cartoonish visual elements	Value and competency	VC1	Accessibility to create virtual content
	SE4	Harmony with the usage scenarios		VC2	Tasks and achievements
	SE5	Stylized art effects		VC3	Quantifiable results
Feeling of immersion	FI1	Integration of virtual content with reality	Social experience	SO1	Direct player-to-player interaction
	FI2	Complete basic worldview		SO2	Buddy system
	FI3	Appropriate place of virtual content		SO3	Avatar (indicator of the presence of other users)
	FI4	Conformity to the basic laws of reality		SO4	Active social communication

	FI5	Reasonable but unexpected virtual content		SO5	Passive social communication
	FI6	Appropriate and consistent art style	Physical activity	PA1	Open world to be explored
Gameplay mechanics	GM1	Parallel interactions		PA2	Sports competitions
	GM2	Massive competition	Personal security	PS1	Delineation of activity boundaries
	GM3	Interact with physical elements		PS2	Warning of security risk
	GM4	Appropriate virtual props and interaction media			

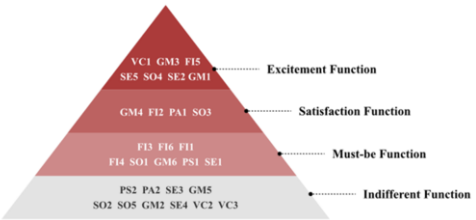

Figure 3. Prioritization of functional attributes.

4. Application of Design Strategies

4.1. Material Preparation

We developed ParallelWorld with the design strategies of MSynAR-IEPOS. ParallelWorld is a medium for users to perceive and interact with the virtual world that parallels the real one. Figure 4 demonstrates its basic worldview. It offers experiences of reality and virtuality, including scene exploration, content creation, and multiplayer collaboration. In addition to general functions like shuttling through parallel worlds and taking photos, we designed rich materials and activities for each of the three basic modes of MSynAR interaction (Figure 5).

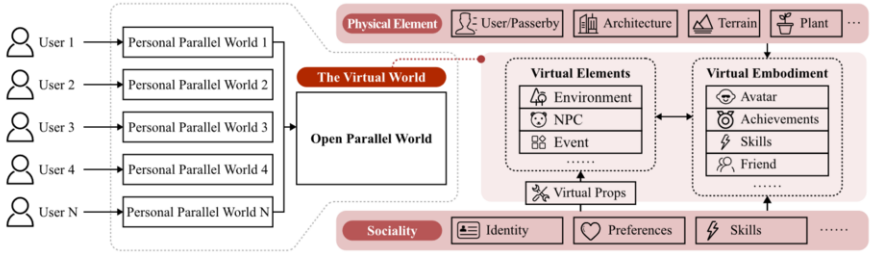

Figure 4. Structure of the worldview in ParallelWorld.

Figure 5. Props and activities for interaction in ParallelWorld.

As the application space, we chose an outdoor cross-street area in Hangzhou (Figure 6). The following are the reasons for it: (1) the wide outdoor site meets the requirements of open space; (2) it is adjacent to a large shopping mall, and the demand for entertainment is prominent; (3) it is representative as a study case, due to a moderate flow of people and rich inherent elements of the real environment; (4) it is a pedestrian neighborhood with gentle terrain, so the safety risk is low.

To ensure a smooth experience, we combined 3D reconstruction and GPS to track the user's position and posture, and utilized edge computing to lower latency in instant communication.

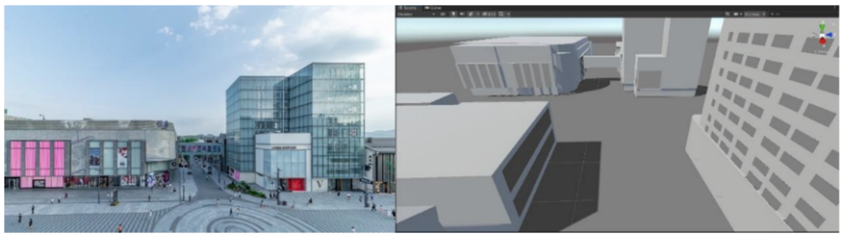

Figure 6. ParallelWorld's application scenario with its 3D model.

4.2. Participants and Procedure

We gathered 24 potential target users to evaluate the experience of ParallelWorld. Participants included 13 males and 11 females with an average age of 24.9 years. All participants are familiar with mobile applications and have a basic understanding of AR products. We divided the 24 participants into four groups. Each group had 15-20 minutes to experience each prop and multiplayer-synchronized interaction with their smartphones or tablets. Afterwards, each participant individually completed the System Usability Scale (SUS), which quantifies user experience and reflects the product system's usability (Jordan et al. 1996). One participant from each group received an interview as supplements to quantitative data.

4.3. Results and Discussion

The results of usability test and user interview suggest that ParallelWorld delivers a qualified multiplayer-synchronized entertainment experience, confirming the effectiveness of the MSynAR-IEPOS design strategies. According to the SUS score reference standard (Jordan et al. 1996), ParallelWorld has the excellent grade for satisfaction, usability, and ease of learning (Table 5).

Table 5: Results of SUS analysis.

Satisfaction	Usability	Learnability
81.25	79.17	82.64

Users in the interview further affirmed that ParallelWorld enhances sensory experience, immersion, and social experience, enriches gameplay mechanisms, promotes physical activity, and reduces physical risks. They also pointed out some drawbacks, focusing on the unstable virtual elements in weak networks, the lack of balance between the ease of use and openness of some props, and the problem of multiplayer communication in noisy outdoor environments. Besides, they expected more expressive feedback, richer props, and customizable avatars in the future.

5. Conclusion

Integration of open space and MSynAR is a new topic in AR entertainment. The paper starts with a systematic overview of the features and critical design problems of MSynAR-IEPOS. To form a holistic solution, this study proposes a set of design strategies (including design elements, design framework, and functional attributes with priority ranking) with relatively universal applicability. Finally, we developed ParallelWorld as an application example and gained positive user feedback.

The design strategy and application example mentioned above can give effective references for the design and iteration of MSynAR-IEPOS and other MSynAR products. In product design, there is a challenge in balancing usability and flexibility when it comes to the creative tools. Optimization is needed in both the interactive form and the medium of interaction for these tools. Additionally, the instability of the visual positioning system leads to drifting of scene elements, requiring further optimization in both technical and design solutions. Although the research process is inevitably subject to subjective and objective limitations, there is still space for optimizing and deepening. Apart from responding to users' expectations for better AR applications on mobile phones, we also hope to explore other interaction mediums and further expand the universality of the design strategy.

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