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Beyond Static Aids: A Contextual AR Framework for Prospective Memory Retrieval

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***Abstract*—Event-Based Prospective Memory (EBPM) is essential for everyday functioning yet prone to failure, particularly in older adults and people with cognitive impairment. This project introduces EB-VMEM, a mobile Augmented Reality (AR) framework that uses on-device, real-time object detection to deliver contextually anchored reminders tied to physical objects. EB-VMEM's system architecture comprises three coordinated subsystems — an Object Detection Subsystem (real-time object recognition via Niantic Lightship), a Memory Subsystem (local object→task associations), and a Cue Display Subsystem (spatially anchored AR text overlays and short audio cues) — that together enable reminders to appear precisely when and where a registered object is encountered. Implemented in Unity with the Niantic Lightship SDK, the prototype emphasizes privacy through on-device inference, low cognitive load via automatic timely cues, and ecological integration by anchoring prompts in the user's real environment.**

Remaining work includes comprehensive user studies to measure effects on task completion, cognitive load, and acceptance, and extensions such as LLM-driven contextualization and wearable AR support.

***Index Terms*—Prospective Memory (PM), Event-Based Prospective Memory (EBPM), Augmented Reality (AR), Object Detection, Reminder System, EB-VMEM, Cost-Effective, Ecological Integration.**

I. Introduction

Prospective memory (PM) represents one of the most critical yet vulnerable aspects of human cognition, enabling individuals to remember to perform intended actions at appropriate future instances. Unlike retrospective memory, which involves recalling past events or learned information, prospective memory demands that individuals initiate actions when encountering specific environmental cues (event-based) or at designated times (time-based). The practical importance of prospective memory cannot be overstated—from remembering to take medications when seeing a pill bottle, to completing work tasks when entering one's office; everyday functioning relies heavily on successful prospective memory [1, 2, 3].

Within PM, **event-based prospective memory (EBPM)** refers to remembering to act when a specific event or cue is encountered, as opposed to **time-based prospective memory (TBPM)**, which depends on self-initiated monitoring of elapsed time [4, 5]. Failures in EBPM are common across the lifespan and are particularly pronounced in populations with mild cognitive impairment (MCI), Alzheimer's disease (AD), and other neurocognitive disorders [6].

EBPM tasks require individuals to remember to perform a previously planned action when they encounter a specific environmental cue or event. The fundamental challenge lies in detecting the prospective memory cue while engaged in ongoing activities, then successfully retrieving and executing the intended action [1, 2].

According to the *multiprocess framework*, event-based prospective memory can operate through two distinct mechanisms: strategic monitoring and spontaneous retrieval [7]. Distinctive, salient cues are more likely to capture attention automatically and trigger intention retrieval. Research using event-related potentials (ERPs) has identified neural components associated with cue detection and stimulus processing [5, 8].

Traditional approaches to supporting PM—such as alarms, calendars, and written notes—often lack contextual specificity and may not align with the cognitive mechanisms underlying EBPM. Augmented reality (AR), by contrast, offers the potential to deliver reminders precisely when and where they are needed, leveraging real-world object recognition and spatial context to trigger intentions [9].

Augmented reality technology offers unprecedented opportunities for cognitive augmentation by seamlessly integrating digital information with the physical environment. Unlike virtual reality, which replaces the real world, AR enhances real-world perception by overlaying contextually relevant digital content [10, 11].

While substantial research has investigated prospective memory mechanisms and age-related decline, and separate work has explored AR applications for various cognitive tasks, limited research has specifically examined AR-based systems that leverage real-world object detection as event-based cues for prospective memory support. Most existing memory aids rely on time-based reminders (smartphone notifications, sticky notes) or static cues, rather than actively detecting environmental cues and providing contextually appropriate interventions [10, 11, 12].

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II. Related Work

While EBPM and TBPM rely on overlapping neural networks, event-based tasks show unique activation patterns related to cue monitoring and depend more on environmental cues, unlike time-based tasks that involve self-initiated monitoring [5].

External memory aids like notes and object placement improve prospective memory. However, their nature is static and electronic reminders are not context-aware [12, 13]. Process-based and strategy-based training, such as implementation intentions and rehearsal, can improve prospective memory in older adults, but effects often diminish over time, highlighting the need for interventions that support real-world functioning [14, 15].

AR is used in healthcare for navigation and motor cuing, and for cognitive rehabilitation by supporting spatial navigation and memory. Previous AR memory interventions often used abstract or non-object cues [11, 12]. Early projects like *NeverMind* explored AR for memory palace techniques, while recent work focuses on leveraging object detection and spatial anchoring to support task recall [9, 11, 15].

Advances in AR and computer vision now allow real-world object detection in mobile apps, which research shows is more memorable and effective as a cue compared to images or 2D stimuli [15, 16]. Contextual triggers—such as recognizing a registered object in the camera view—can be used to deliver timely reminders, leveraging the automaticity of event-based retrieval processes [17, 18]. The **Niantic Lightship SDK** for Unity provides robust APIs for object detection, semantic labeling, and spatial anchoring, facilitating the development of scalable, cross-platform AR memory aids [17, 18].

III. Problem Statement

The challenge is to design and implement a Mobile Augmented Reality (AR) framework for smartphones that directly addresses prospective memory failure, which is the difficulty in remembering to perform an action at a future time or specific location. This framework will work by replacing disruptive traditional notifications with context-aware AR reminders; specifically, it will use the phone's sensors to recognize a predefined physical trigger location (like keys or a specific desk) and then display the reminder as a digital overlay anchored to a relevant object in the user's real-world view, thereby providing a more intuitive, spatial, and timely prompt that significantly increases the user's chance of successfully executing their intended action.

IV. System Design

The AR prospective memory support system, which we name EB-VMEM, comprises three primary components as shown in Figure 1:

1) Object Detection Subsystem: The Lightship Object Detection Subsystem sends real-time detection information in the form of *XRObjects*, with a list of 206 pre-trained object classes. These classes include *person*, *bus*, *car*, and *flag*. Some of these, in turn, contain their respective subclasses; for example,

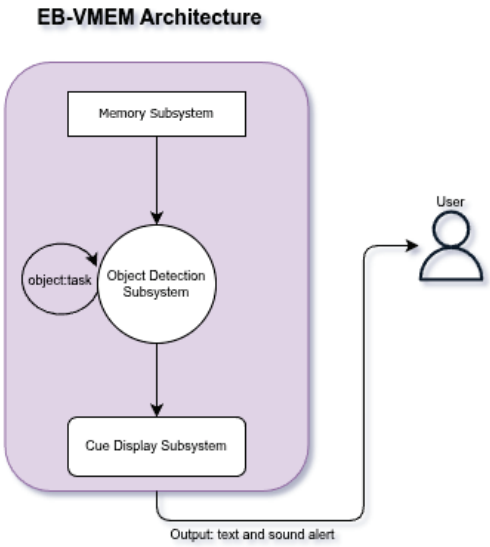

Fig. 1. System Architecture.

glasses, *sunglasses*, and *goggles* are subclasses of the *glasses* class; likewise, *fast food*, *hot dog*, *French fries*, and *cookies* are subclasses of the *food* class.

2) Memory Subsystem: The memory subsystem stores information in the form of key-value pair associations. An object is stored in the memory with the associated task (key: object name, value: task).

3) Cue Display Subsystem: The cue display subsystem is responsible for reminding the user to perform an intended action by displaying text while playing a sound that will trigger the prospective memory (value, task).

When an object (key) from the memory subsystem is matched with one of the 206 pre-trained object classes by the Object Detection Subsystem, the Cue Display Subsystem is activated and the task (value) is displayed to the user monitor followed by a sound.

The system follows a context-aware computing paradigm, where environmental conditions (presence of specific objects) trigger appropriate informational interventions (task reminders). This approach aligns with theoretical frameworks emphasizing the importance of cue detection in event-based prospective memory.

V. Methodology

A. Development Environment

To achieve the proposed objectives, the following tools were utilized:

- **Unity 6000.0.58f2 LTS** as the primary development platform. Unity was selected due to its cross-platform capabilities, robust AR support, and extensive developer community. It served as the core engine for creating the MobileAR application.

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- **Niantic Lightship 3.17 SDK** (formerly Lightship ARDK) for AR functionality. The Niantic Lightship SDK was integrated to leverage advanced AR features, specifically real-time object detection [17, 18].

This technology stack was selected for its cross-platform compatibility, robust AR features—including object detection and occlusion handling—and extensive developer community support.

B. Object Detection Subsystem

The Object Detection Subsystem is implemented by leveraging the Niantic Lightship framework. Lightship's Object Detection subsystem enhances contextual awareness by creating semantically labeled 2D bounding boxes that dynamically update as real-world objects appear on-screen.

By placing Lightship's ARObjectDetectionManager in the scene and subscribing to the ObjectDetectionsUpdated event, the system receives real-time detection information in the form of XRDetectedObjects. The system also listens to the MetadataInitialized event to retrieve the list of available object classes once the model is ready. An ObjectRecognition.cs script was created to manage this component and is attached to an empty Object Recognition Game Object.

Identification Scene Initialization: The Object Recognition Manager activates when the identification scene is initialized. It registers the OnMetadataInitialized event; once the feature is ready, it registers ObjectDetectionsUpdated to automatically receive detection results.

Processing Detections: The ObjectDetectionsUpdated function collects the results and presents them to the user. Since each result can contain multiple object categories, the system filters and sorts the results by their confidence values to display only the most likely classification.

C. Memory Subsystem

The Memory subsystem performs two primary functions: Store the classes of objects and create association between the objects and the tasks that will trigger prospective memory. Figure 2 illustrates the user-facing association process.

- **User Workflow:** Users select a target object name, enter a specific task, and save the association locally (Figure 2).
- **Data Structure:** Each object-task pair is stored with the object name serving as the unique identifier.
- **Recognition Matching:** Upon detection, the system matches the recognized object to registered entries using feature descriptors and confidence scores.

D. Cue Display Subsystem

The Cue Display Subsystem manages the output presented to the user, acting as the bridge between the Object Detection Subsystem and the associations stored in the Memory Subsystem.

The system triggers the Cue Display Subsystem when the Object Detection Subsystem recognizes a real-world object that exists as a registered "object:task" association. When a match occurs, a text overlay is displayed on the screen as shown in figure 3, accompanied by a short audio alert to stimulate the user's prospective memory.

Fig. 2. Object-Task Association.

- **Contextual Reminders:** When a registered object is detected, a reminder overlay appears displaying the associated task for 10 seconds.
- **Reminder Frequency:** To maintain effectiveness without causing notification fatigue, the reminder is repeated every 60 minutes for any specific task.

VI. Results and Discussion

This project presents the design and implementation of a MobileAR-based prospective memory support system. The system was successfully developed and tested for technical functionality on smartphones, demonstrating reliable real-time

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object detection and user-driven task associations within simulated scenarios. Informal technical validation establishes core system capabilities, confirming that MobileAR can deliver contextually triggered memory cues when registered objects are detected in the environment.

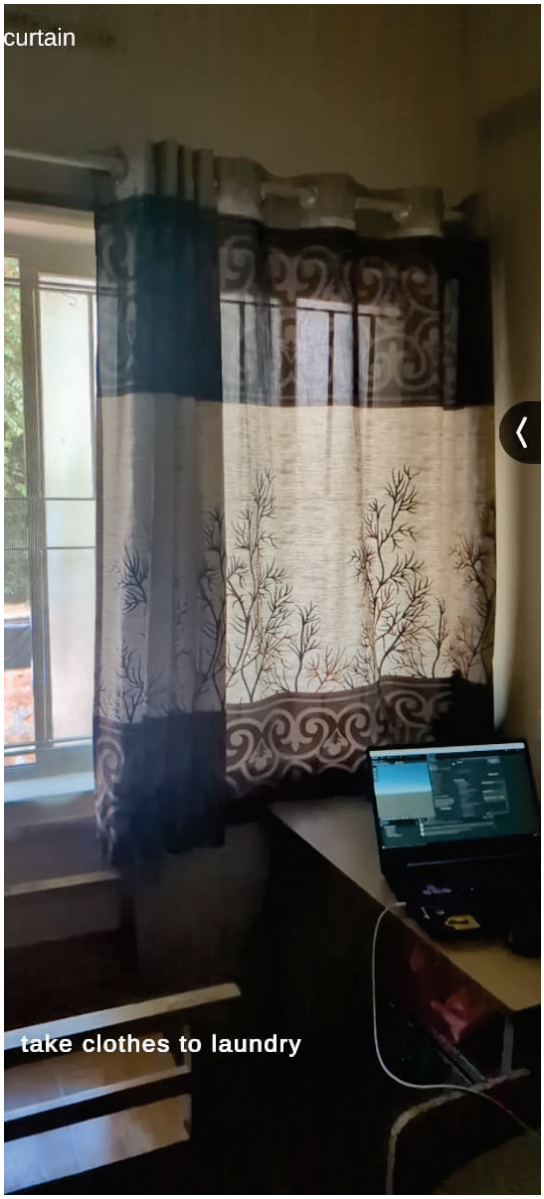

Fig. 3. Object Detection and Task Overlay.

The developed MobileAR system demonstrates technical feasibility for real-time detection and context-aware reminder delivery using smartphones. By leveraging real-world object recognition as event-based cues, the application provides a novel approach to prospective memory support that can potentially enhance cue salience, reduce monitoring burdens, and improve ecological integration [10, 11, 15, 19].

This work contributes to event-based prospective memory augmentation in naturalistic environments. While traditional memory aids rely on time-based reminders or static cues, AR enables digital interventions to appear precisely when the relevant object is encountered, anchoring cognitive support in physical space. This aligns with theoretical models emphasizing the value of salient, spatially relevant cues for automatic intention retrieval [11, 12, 15].

The system grounds prospective memory theory in practical AR design, suggesting that real-world object cues offer distinct advantages for event-triggered intention retrieval. The approach integrates contextual computing principles with established cognitive research, providing a bridge from laboratory paradigms to real-world environments—at least at a prototype stage.

VII. Conclusion

This project has successfully demonstrated the technical feasibility of EB-VMEM, an Augmented Reality (AR) framework designed to mitigate event-based prospective memory (EBPM) failures through real-time, context-aware assistance. While traditional memory aids like alarms and notes remain largely static and time-dependent, this research proves that MobileAR can effectively bridge the gap between planned intentions and environmental cues.

By leveraging the Unity engine and the Niantic Lightship SDK, the developed system provides a robust platform for associating tasks with physical objects, such as doorways or pill bottles, and triggering digital overlays precisely when those objects are detected in the user's environment. Technical validation confirmed that the system can perform on-device inference to maintain user privacy while delivering salient, spatially-anchored reminders that align with natural cognitive processes.

However, the transition from technical prototype to a practical cognitive tool requires addressing several critical frontiers. The current reliance on handheld smartphones imposes ergonomic and battery constraints that may hinder long-term habituation. Furthermore, while initial performance metrics are promising, comprehensive user-centered studies are essential to quantify the system's impact on actual task completion rates and cognitive load in real-world settings.

The ultimate potential of this work lies in its evolution toward wearable AR glasses, which will enable seamless, hands-free cognitive augmentation. By grounding AR design in the principles of prospective memory theory, this project establishes a foundation for future "ubiquitous memory assistants" that empower individuals—particularly those with cognitive impairments—to navigate their daily lives with greater autonomy and confidence.

VIII. Future Directions

To build upon the current prototype and address the limitations of static object-to-task mapping, several avenues for future research are proposed:

LLM Integration for Dynamic Context: Integrating Large Language Models (LLMs) could allow the system to interpret complex environments. Rather than simple key-value pairs, the system could understand that detecting a "backpack" on

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a ”Friday morning” implies a reminder for ”gym clothes,” providing a more nuanced layer of cognitive support [13, 19].

Enhanced Spatial Persistence: Future iterations will leverage advanced spatial anchoring to ensure that reminders remain locked to physical objects even when the user moves the smartphone camera away, utilizing the full potential of the Niantic Lightship persistence APIs [17, 20].

Wearable AR Integration: Moving the framework from smartphones to AR glasses would further reduce the ”monitoring burden,” allowing cues to appear naturally in the user’s field of vision without the need for active handheld device interaction [9, 21].

Personalization and Adaptation: Future versions could implement machine learning algorithms to track ”hit rates” of intended actions, automatically adjusting the salience (size, color, or sound) of reminders based on the user’s past performance [1, 14].

User-Centered Evaluation: The next key step is conducting comprehensive user studies to measure the system’s impact on prospective memory performance, cognitive workload, and user acceptance. Such studies should recruit target populations and deploy the app in daily-life settings, comparing AR-based reminders to traditional aids.

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