IoT-Enabled Environment Illuminance Optimization for Augmented Reality

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In order to provide high quality augmented reality (AR) experiences, environmental conditions such as light level must be conducive to a high level of virtual content stability, accurate eye tracking and good virtual content visibility. This is challenging due to the dynamic nature of environmental conditions and AR application requirements. In this poster we present the first automatic environment optimization system for AR which adapts to both environment lighting and texture. First we conduct experiments that demonstrate the effect of light level on virtual object stability and eye tracking. We then detail our edge computing system architecture which uses IoT devices to sense and adjust environment conditions, and lays the foundation for future environment-aware AR applications.

CCS Concepts: • **Human-centered computing → Mixed / augmented reality**.

Additional Key Words and Phrases: Augmented reality, IoT, environment optimization, edge computing

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1 INTRODUCTION

Augmented reality (AR) apps are becoming more and more commonplace in home, business, educational, medical and industrial settings. However, these apps are usually deployed with little to no consideration of how properties of the surrounding environment affect user experiences and task performance. In recent years IoT devices such as smart light bulbs and HVAC systems have been employed to automatically optimize environments for occupant comfort and environmental energy efficiency. A natural yet unexplored extension is the use of IoT devices to optimize environments for AR experiences.

AR experiences are affected by environmental conditions in a variety of ways. All AR applications depend on the visibility of recognizable textures for positioning virtual content, whether fiducial markers or images in marker-based AR, or natural environment features in markerless AR. If these textures are not distinguishable then device pose estimates are inaccurate; this results in unstable virtual content, destroying the user's sense of immersion. The visibility of virtual content is also affected by lighting and textures in the surrounding environment, especially on the optical see-through displays of modern AR headsets (e.g., the Microsoft HoloLens 2). Furthermore, headsets facilitate interaction and cognitive state detection through eye tracking, the performance of which can be impacted by environment lighting.

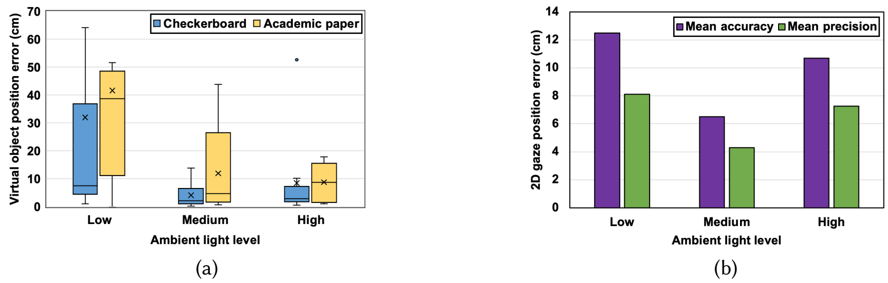


Fig. 1. AR system performance in low (50–100 lux), medium (150–450 lux) and high (500–1000 lux) ambient light levels: virtual object stability on the Samsung Galaxy Note 10+ with different environment textures (a), and eye tracking error on the Magic Leap One (b).

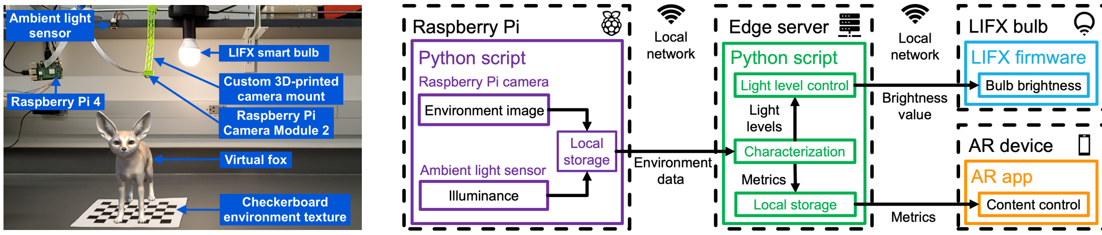
These environmental requirements within AR are often in conflict with each other, as well as external factors such as environmental energy efficiency. They are also dynamic; external light sources, environment textures, as well as the AR applications and devices to optimize for, change over time. We therefore require a system that automatically senses and adjusts environmental conditions to the optimal level for the current AR users. Drawing inspiration from existing IoT-based environment optimization systems for smart homes [3] and street lighting [4], in this work we study the requirements for, then develop, *the first automatic environment optimization system for AR that adapts to both environment lighting and textures*. Our extendible proof-of-concept detects current environmental conditions using an IoT camera and a light sensor, and adjusts light levels accordingly using a smart bulb.

2 IMPACT OF ENVIRONMENT LIGHT LEVEL IN AUGMENTED REALITY

In this section we conduct experiments to study how two aspects of AR system performance, virtual content stability and eye tracking, are impacted by environment light levels.

Virtual content stability: For markerless AR, which uses VI-SLAM (Visual-Inertial Simultaneous Localization and Mapping) to position content, we previously developed a method to measure virtual object stability on AR platforms, based on placing virtual spheres on a real-world reference point [6]. We now use it to examine the effect of ambient light level on virtual object position error, after a user walks away (approx. 7m) from a virtual object, then returns. We conducted our experiments in a university lab, on a Samsung Galaxy Note 10+ smartphone (ARCore v1.28). We tested two textures where the virtual object was placed, a checkerboard and an academic paper, in three ambient light levels (low, 50-100 lux; medium, 150-450 lux; high, 500-1000 lux), with 10 trials for each of the six settings. Our results (Figure 1a) show that content stability declines in lower light, but that the checkerboard was more robust to this effect than the academic paper (mean errors of 4.1cm and 12.0cm respectively in medium light). We observed that in medium light, noise in smartphone camera images has minimal effect on the checkerboard texture, but obscures the finer texture of the academic paper, making VI-SLAM-based place recognition more challenging, and resulting in greater error.

Eye tracking: AR headsets such as the Microsoft HoloLens 2 and the Magic Leap One employ video-oculography for eye tracking; gaze position is calculated in the coordinate system associated with the VI-SLAM-based spatial map by extracting features (e.g., pupil center) from infrared images of the eye. At low light levels, gaze estimate error may increase due to less accurate spatial mapping, as well as dilated pupils being partially covered by the eyelid; high light levels can make pupil detection more challenging due to reflections and glare from ambient sources [5]. We conducted experiments to measure 2D gaze position error on the Magic Leap One AR headset, in the three light conditions (low, medium and high) described above. In an IRB-approved user study, four participants (all male, aged 18–24) were instructed to look at nine circular targets arranged in a 3x3 grid, on a 1m x 0.67m virtual screen placed 2.5m in front of



(a) (b)

Fig. 2. Our IoT-enabled environment optimization system for AR: viewed through our custom AR app (a) and architecture diagram (b).

them, while keeping their head still. The nine targets were presented in turn for 10s each, while estimated gaze position was recorded at 30Hz. Five trials were conducted with each participant at each light level. Our results (Figure 1b) show that both the accuracy (2D standard distance) and precision (standard deviation) of 2D gaze position estimates degrade at low and high light levels. For example, mean accuracy was 6.5cm in medium light, but 12.5cm in low light.

3 SYSTEM DESIGN

Based on our results we developed a proof-of-concept environment optimization system (Figure 2a) in which ambient light in an AR environment is automatically maintained at a sufficient level for high virtual object stability, and where possible, accurate and precise eye tracking. As such the default optimum light level is 300 lux. However when the environment contains fine visual textures, then the core AR functionality, virtual object stability, is prioritized and that optimal level is increased to 750 lux. To offload the computationally expensive environment texture characterization task, while avoiding transfer of potentially sensitive images to the cloud, we implement an edge computing architecture, with optimization controlled by a server on the same wireless local area network, as shown in Figure 2b.

An 8MP Raspberry Pi Camera V2 and an ambient light sensor (TSL25911FN), connected to a Raspberry Pi 3 Model B+, record images of the environment and illuminance every 5s. This environment data is saved to local storage then sent via an HTTP PUT request to the edge server (a high-end desktop computer). The characterization module determines the optimal light level by detecting the number of FAST corners in the environment image using OpenCV: if more than 250 corners are detected the environment texture is classified as fine, and the optimal light level is raised. If a light level change is required, the characterization module sends the optimal and current light levels to the light level control module, which adjusts the brightness value of the LIFX bulb accordingly, at low latency (<0.5s). Environment characterization metrics (illuminance, plus image brightness, contrast, edge strength and corners) are also stored on the edge for long-term trend analysis, while the latest metrics can be requested by an AR device via an HTTP GET request.

Our future work will extend the current system in three key ways. First, we will add sensors to monitor multiple regions of an environment, and test adjusting light and texture using smart blinds, displays and projectors. Second, we will study how virtual content visibility is impacted by light level [1], background color [2], and factor that into our environment optimization rules. Third, we will explore how AR content can be contextualized or optimized for current environmental conditions, and AR apps can communicate specific environmental requirements.

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