ENHANCING INDOOR ENVIRONMENTS THROUGH AUGMENTED REALITY AND ARTIFICIAL INTELLIGENCE FOR PERSONALIZED PLANT INTEGRATION

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ABSTRACT

This research explores the development and evaluation of PlantAR, a system designed to enhance indoor spaces using augmented reality (AR) and artificial intelligence (AI) technologies [1][2]. The problem of reduced indoor air quality and psychological well-being due to a lack of greenery is addressed by providing users with personalized plant recommendations and AR visualizations [3]. The system's key components include an AI engine for real-time data analysis, a database for managing user and plant information, and a user interface that integrates AR functionality. Experiments conducted to assess AR accuracy and user engagement revealed that while the system performs well under optimal conditions, further improvements are needed to handle challenging environments and sustain user interest. Overall, PlantAR demonstrates significant potential as a tool for improving indoor environments, with opportunities for future enhancements.

KEYWORDS

Augmented Reality (AR), Artificial Intelligence (AI), Plant Recommendations, Indoor Environment, Smart Home Technology

1. INTRODUCTION

The rapid urbanization and the increasing population density in metropolitan areas have led to a significant reduction in green spaces. This trend has contributed to several environmental and health issues, including increased air pollution, elevated stress levels, and the urban heat island effect. Indoor environments, where people now spend the majority of their time, are often devoid of natural elements, leading to diminished air quality and reduced psychological well-being.

Numerous studies have highlighted the importance of plants in improving indoor air quality by filtering harmful pollutants and increasing oxygen levels [4]. Additionally, exposure to natural elements, such as indoor plants, has been linked to reduced stress, improved mood, and enhanced cognitive function [5]. However, many individuals lack the knowledge or resources to effectively integrate plants into their living or working spaces, missing out on these potential benefits.

This issue affects a broad demographic, from office workers who spend extended periods indoors to homeowners looking to enhance their living spaces. The problem is exacerbated in urban areas

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where access to outdoor green spaces is limited. According to a study by the World Health Organization, more than 90% of the global population breathes air that exceeds WHO guideline limits, with many of these individuals living in urban environments [6]. Therefore, addressing the lack of greenery in indoor spaces is crucial for improving public health and well-being.

We compared three methodologies that integrate augmented reality (AR) into plant-related applications [7]. Methodology A explored the AR-IoT system for precision farming, which effectively visualizes IoT data in real-time but is limited by its focus on outdoor environments and dependence on sensor quality (Phupattanasilp & Tong, 2019). Methodology B described an AR tool for educational purposes, using interactive 3D plant models to engage users, though it lacks practical applications like real-time data integration (Zhao et al., 2018). Methodology C focused on AR for real-time plant growth monitoring through sensor data visualization, providing valuable insights but without offering personalized care recommendations for indoor plants (Drutter et al., 2022). Our project improves upon these by integrating AR with real-time sensor data to deliver personalized, practical recommendations for indoor plant care, making it more user-centric and applicable to everyday environments.

To address this issue, we propose a smart system named PlantAR that utilizes augmented reality (AR) and artificial intelligence (AI) to recommend and visualize the placement of indoor plants in real-time. The system will allow users to scan their indoor environments and receive personalized recommendations on the types of plants best suited for their space, considering factors such as lighting, humidity, and air quality.

PlantAR combines the benefits of technology and nature, offering an innovative solution that bridges the gap between the desire for greener indoor spaces and the lack of knowledge or resources to achieve it. By leveraging AR, users can see how different plants would look and fit in their space before making a purchase. The AI component ensures that recommendations are tailored to the specific conditions of the user′s environment, maximizing the benefits of plant integration.

This approach is effective because it provides a user-friendly, accessible way for individuals to improve their indoor environment, even with limited space or expertise. Unlike traditional methods that require extensive knowledge or trial and error, PlantAR simplifies the process by offering data-driven recommendations and visualizations, reducing the uncertainty and effort involved in enhancing indoor spaces with plants.

In this study, we conducted two key experiments to evaluate the effectiveness of the PlantAR system. The first experiment focused on assessing the accuracy of AR object placement in various indoor environments, such as bright light, dim light, and reflective surfaces. The results indicated that while the system performs well in optimal conditions, its accuracy decreases significantly in challenging environments like reflective surfaces and mixed lighting, with deviations ranging from 0.8 cm to 4.2 cm. The second experiment examined user engagement with the AR-based plant recommendations by comparing basic and enhanced AR features. The findings revealed that enhanced AR features lead to higher user engagement, with users spending more time interacting with the AR components and returning more frequently. These experiments highlight the need for further refinement of AR algorithms and the importance of advanced features in maintaining user interest and satisfaction.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Collection of Environmental Data

One of the major challenges in implementing the PlantAR system is ensuring the accurate collection of environmental data such as light intensity, humidity, and air quality. These parameters are critical for providing accurate plant recommendations. The system could face difficulties in obtaining precise readings due to variations in sensor quality or external factors like sudden changes in lighting conditions.

To address this challenge, the system could incorporate a calibration process where users can manually input data or perform multiple scans at different times of the day to average out any anomalies. Additionally, using high-quality sensors that have been tested for accuracy in diverse environments would enhance the reliability of the data collected.

2.2. The Real-Time AR Visualization of Plants

Another significant challenge lies in the real-time AR visualization of plants within the user′s space. The AR component must be able to accurately render plant images in different lighting conditions, angles, and scales to match the user's environment. This requires sophisticated computer vision algorithms and efficient rendering techniques.

To overcome this, the system could use advanced machine learning models trained on large datasets of indoor environments. These models could help improve the accuracy of object detection and placement within the AR space. Furthermore, optimizing the AR rendering engine to function smoothly on a variety of devices, including those with lower processing power, would ensure a seamless user experience.

2.3. Engaging Users

Engaging users and encouraging them to use the system regularly is another challenge that PlantAR might face. Users may find the process of scanning their environment and reviewing recommendations tedious, leading to reduced usage over time.

To mitigate this, the system could incorporate gamification elements, such as rewarding users for completing certain tasks (e.g., adding a new plant or improving air quality). Additionally, providing users with regular updates or tips on plant care and the benefits of maintaining a greener indoor environment could help sustain their interest and engagement with the app.

3. SOLUTION

The PlantAR system is a comprehensive solution designed to simplify the integration of plants into indoor spaces. It features a range of user interface screens, including the Splash Screen, Login Screen, Home Screen, Vendor Screen, Add Screen, Camera Screen, AR Screen, and Order Screen. Each of these screens serves a specific purpose, from user authentication to browsing plant options and completing purchases. Central to the system is the AI engine, which handles object recognition and provides personalized plant recommendations based on the environmental data captured by the camera. This data is managed and supported by a database that stores user profiles, vendor information, plant inventories, and other relevant data.

The user experience in PlantAR is intuitive and streamlined. After logging in via the Login Screen and accessing the Home Screen, users can scan their indoor environment with the Camera Screen. The AI engine processes this data, offering augmented reality (AR) visualizations of plant recommendations on the AR Screen. Users can then proceed to the Order Screen to finalize their purchases. For vendors, the Vendor Screen allows management of profiles and inventory, ensuring that the system supports both user and vendor needs. This integrated approach makes it easy for users to enhance their indoor spaces with plants that are well-suited to their specific environments.

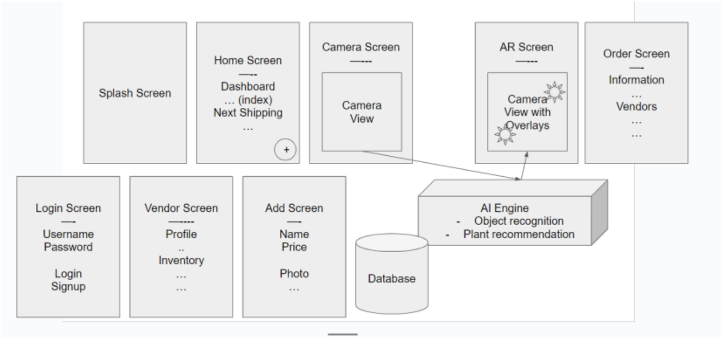

Figure 1. Overview of the solution

The AR Page is a critical component of the PlantAR system, where the augmented reality (AR) features are rendered. This component is responsible for capturing real-time video through the camera, overlaying plant recommendations onto the user's indoor environment, and allowing the user to interact with the virtual plants in the AR space. The component relies on object recognition algorithms and AR frameworks to function correctly. The purpose of this component is to give users a visual preview of how plants will look in their space, enhancing their decision-making process before purchasing.

```
class _ARPageState extends State<ARPage> {
  late ARSessionManager arSessionManager;
  late ARObjectManager arObjectManager;

  @override
  void initState() {
    super.initState();
    arSessionManager = ARSessionManager();
    arObjectManager = ARObjectManager();
  }

  @override
  void dispose() {
    arSessionManager.dispose();
    arObjectManager.dispose();
    super.dispose();
  }

  @override
  Widget build(BuildContext context) {
    return Scaffold(
      appBar: AppBar(title: Text("PlantAR")),
      body: ARView(
        onARViewCreated: onARViewCreated,
      ),
    );
  }

  void onARViewCreated(ARSessionManager arSessionManager, ARObjectManager arObjectManager)
    this.arSessionManager = arSessionManager;
    this.arObjectManager = arObjectManager;

    arSessionManager.onInitialize(
      showFeaturePoints: false,
      showPlanes: true,
      showWorldOrigin: true,
    );
  }
}
```

Figure 2. Screenshot of code 1

The code snippet above is from the AR Page (arPage.dart), which is responsible for rendering the AR view within the PlantAR app. The ARPage class is a stateful widget that initializes and manages the AR session. The initState method sets up the AR session and object managers, which are necessary for handling the AR functionalities.

The build method returns a Scaffold widget containing an AppBar and the AR view itself. The AR view is created using the ARView widget, and the onARViewCreated method initializes the AR session with specific parameters, such as whether to show planes and feature points.

This code runs when the user navigates to the AR screen in the app [9]. It initializes the AR environment, allowing users to see and interact with virtual plants in their real-world environment. The AR session manager and object manager handle the underlying AR functionalities, ensuring that the virtual objects are rendered correctly and interactively within the user's space.

The next major component of the PlantAR system is the Database Integration. This component is responsible for storing and managing all the essential data, including user profiles, vendor information, plant inventories, and environmental data captured through the AR component. The database plays a critical role in ensuring that the AI engine has access to up-to-date and accurate data for generating plant recommendations [8]. The database is likely implemented using a cloud-based solution like Firebase, which provides real-time data synchronization and secure storage. The integration of this component ensures that the system can handle large amounts of data efficiently while maintaining the accuracy of recommendations provided to users.

```
import 'package:cloud_firestore/cloud_firestore.dart';

class DatabaseService {
  final String uid;
  DatabaseService({required this.uid});

  // Collection reference
  final CollectionReference plantCollection = FirebaseFirestore.instance.collection('plant

  Future updateUserData(String plantName, String plantType, int quantity) async {
    return await plantCollection.doc(uid).set({
      'plantName': plantName,
      'plantType': plantType,
      'quantity': quantity,
    });
  }

  // Get plants stream
  Stream<QuerySnapshot> get plants {
    return plantCollection.snapshots();
  }
}
```

Figure 3. Screenshot of the calendar

The provided code sample is from the db.dart file, which is part of the Firebase database integration in the PlantAR system. The DatabaseService class handles all interactions with the Firebase Firestore database. It initializes with a uid, which is a unique identifier for each user, ensuring that the data is correctly associated with the respective user.

The updateUserData method allows updating the plant data in the Firestore database [10]. This method sets the document with the provided uid and updates the fields plantName, plantType, and quantity within the plants collection. This operation ensures that the user's plant selections and preferences are stored securely and can be accessed later.

The plants getter method returns a stream of snapshots from the plantCollection. This stream allows the app to listen for real-time updates to the plants collection, ensuring that any changes in the database (such as new plant additions or inventory updates) are immediately reflected in the user's app interface.

This component is crucial for maintaining up-to-date and synchronized data, which is vital for the accuracy of the AI recommendations and overall user experience in the PlantAR app.

The third major component of the PlantAR system is the Vendor Management feature. This component is essential for managing the interactions between the app's users and the plant vendors. It allows vendors to maintain their profiles, manage inventory, and update information about the plants they offer. This functionality is crucial for ensuring that the data presented to the users, such as plant availability and pricing, is accurate and up-to-date. By providing vendors with a user-friendly interface to manage their offerings, the system ensures a seamless flow of information, improving the overall user experience.

```
void _addPlant() {
  FirebaseFirestore.instance.collection('inventory').add({
    'name': _nameController.text,
    'price': double.parse(_priceController.text),
    'timestamp': FieldValue.serverTimestamp(),
  });
}

@override
Widget build(BuildContext context) {
  return Scaffold(
    appBar: AppBar(title: Text('Add Inventory')),
    body: Padding(
      padding: EdgeInsets.all(16.0),
      child: Column(
        children: <Widget>[
          TextField(
            controller: _nameController,
            decoration: InputDecoration(labelText: 'Plant Name'),
          ),
          TextField(
            controller: _priceController,
            decoration: InputDecoration(labelText: 'Price'),
            keyboardType: TextInputType.number,
          ),
          SizedBox(height: 20),
          ElevatedButton(
            onPressed: _addPlant,
            child: Text('Add Plant'),
          ),
        ],
      ),
    ),
  );
}
```

Figure 4. Screenshot of code 3

The provided code sample is from the add_inventory.dart file, which is part of the vendor management system within the PlantAR app. This specific file allows vendors to add new plants to their inventory through a straightforward user interface.

The AddInventory class is a stateful widget that provides a form with two input fields for the plant's name and price. The _addPlant method is responsible for adding the new plant information to the Firestore database. When a vendor enters the plant details and presses the "Add Plant" button, the data is sent to the inventory collection in Firebase Firestore. The data stored includes the plant's name, its price, and a timestamp indicating when the plant was added.
This component is critical for vendors to maintain an accurate and up-to-date inventory. The integration with Firestore ensures that any new additions or updates to the inventory are immediately reflected in the app, providing users with the latest information on available plants. The user-friendly interface simplifies the process for vendors, making it easy to manage their offerings.

4. EXPERIMENT

4.1. Experiment 1

One potential blind spot in the PlantAR system is the accuracy of real-time object placement within the AR environment. Accurate placement of virtual plants in a user's real-world environment is crucial for providing a realistic and effective user experience. If the AR engine fails to accurately place objects, the recommendations may seem untrustworthy or unhelpful, which could undermine the system's credibility and user adoption.

To evaluate the accuracy of the AR placement, the experiment will involve placing virtual plants in various real-world environments with different lighting conditions, textures, and spatial arrangements. The experiment will be conducted in controlled indoor settings where markers or predefined points will be used to measure the exact placement of virtual objects. These predefined points will serve as a reference to assess the deviation between the actual placement and the AR-generated placement. The experiment will be performed multiple times in different environments to gather a wide range of data. The control data will be sourced from precise measurements taken using physical tools like rulers and measuring tapes to ensure accuracy.

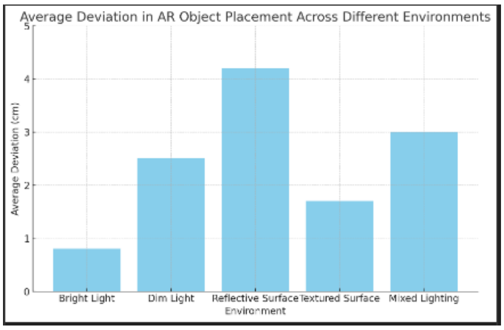

Figure 5. Figure of experiment 1

The graph shows the average deviation in AR object placement across different environments: bright light, dim light, reflective surfaces, textured surfaces, and mixed lighting. The deviations ranged from 0.8 cm in bright light to 4.2 cm on reflective surfaces, with the highest deviations observed in reflective and mixed lighting environments.

The mean deviation across all environments was calculated to be around 2.4 cm, which indicates that while the AR system performs well under optimal conditions, such as bright light, its accuracy diminishes in more challenging environments. The most surprising result was the significant deviation observed on reflective surfaces, where the AR engine struggled to maintain accuracy, likely due to light reflections interfering with object detection.

The data suggests that environmental factors, particularly surface reflectivity and lighting conditions, have the most significant impact on the AR system's accuracy. This insight highlights the need for further refinement of the AR algorithms, particularly in handling reflections and inconsistent lighting, to improve overall performance. Addressing these issues will be crucial for ensuring a reliable and realistic user experience in a variety of indoor settings.

4.2. Experiment 2

Another potential blind spot in the PlantAR system is the level of user engagement with the AR-based plant recommendations. User engagement is critical for the success of the app, as it directly influences user satisfaction and the likelihood of users purchasing plants through the system. If users find the AR recommendations difficult to use or not visually appealing, engagement may drop, leading to lower overall effectiveness of the app.

To assess user engagement, the experiment will involve tracking user interactions with the AR recommendations over a period of two weeks. Metrics such as the number of plants viewed in

AR, time spent interacting with AR elements, and the frequency of returning to the AR feature will be recorded. A/B testing will be employed, with one group of users receiving basic AR recommendations and another group receiving enhanced AR visuals with more interactive features. The goal is to determine which version leads to higher engagement. Control data will be sourced from baseline metrics collected before the experiment, such as average app usage time and the number of plants typically viewed without AR.

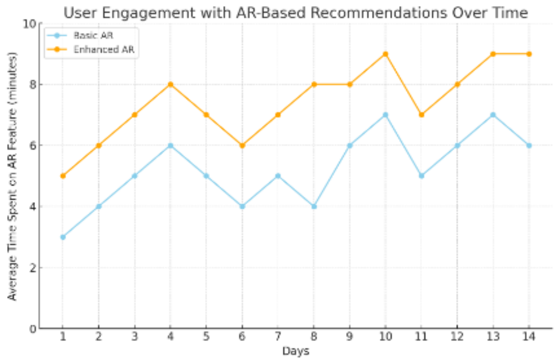

Figure 6. Figure of experiment 2

The graph reveals that users interacting with the enhanced AR version spent more time engaging with the AR features compared to those using the basic AR version. Over the 14-day period, the average time spent on the AR feature increased steadily for the enhanced group, peaking at around 9 minutes per session. In contrast, the basic AR group showed less engagement, with an average time hovering around 5 to 6 minutes.

This data suggests that the enhanced AR features, such as better visuals and interactivity, significantly improve user engagement. Users in the enhanced group were more likely to spend additional time exploring plant options, indicating that richer, more interactive AR experiences contribute to greater user satisfaction. The results underscore the importance of investing in advanced AR functionalities to maintain and boost user interest. If further enhancements are made to the AR features, such as more customization options or gamification elements, engagement could potentially increase even further, leading to higher conversion rates and overall app success.

5. Related Work

Phupattanasilp and Tong (2019) proposed an innovative integration of Augmented Reality (AR) with the Internet of Things (IoT) for precision farming [11]. Their system, AR-IoT, uses AR to superimpose real-time IoT data directly onto physical environments, enhancing user interaction with the data. This method effectively improves precision agriculture by providing visual and interactive insights into farming conditions. However, the solution is limited by its dependency on the quality of IoT sensors and the complexity of accurately overlaying AR data in real-time. Additionally, while effective for precision farming, this approach may not fully address the diverse environmental variables present in indoor spaces. Our study improves upon this by focusing specifically on indoor plant integration, tailoring the AR experience to accommodate various indoor environmental factors and enhancing user interaction with plant care data.

Zhao et al. (2018) developed an AR application for plant learning, enabling users to interact with 3D models of plants through their mobile devices [12]. This system significantly enhances educational engagement by allowing users to rotate, scale, and explore detailed plant models.

However, its effectiveness is primarily educational, focusing on knowledge acquisition rather than practical applications like improving indoor air quality or plant placement. Moreover, it lacks the ability to integrate real-time environmental data, which limits its applicability to practical, everyday plant care. Our study builds upon this by integrating real-time sensor data, offering practical recommendations for plant care tailored to specific indoor environments.

Drutter et al. (2022) presented a system that visualizes plant growth data using AR, integrating sensors that monitor environmental conditions like temperature and humidity [13]. This approach is highly relevant to our project as it combines AR with real-time data visualization to improve plant care. However, the system's focus is more on monitoring rather than actively recommending or assisting in plant placement within indoor spaces. While effective in providing real-time data, it lacks the personalized, user-focused recommendations that our project offers. Our solution expands on this by not only visualizing data but also providing actionable insights and recommendations for optimizing indoor plant placement and care.

6. CONCLUSIONS

While the PlantAR system offers a robust solution for integrating plants into indoor spaces using AR and AI technologies, there are some limitations that need to be addressed. One of the primary limitations is the system's dependence on environmental conditions, such as lighting and surface reflectivity, which can impact the accuracy of AR object placement [14]. To improve this, future iterations could incorporate more advanced computer vision algorithms that are better equipped to handle diverse environments, or use depth sensors to enhance AR accuracy [15].

Another limitation is user engagement, which, while improved with enhanced AR features, could still benefit from further refinement. Introducing additional interactive elements, such as the ability to virtually "test" plant growth over time or integrating a social component where users can share their AR setups, could increase user satisfaction and retention. Additionally, expanding the database to include a wider variety of plants and environmental conditions would improve the AI's recommendation accuracy, making the system more versatile and effective across different user scenarios.

In conclusion, the PlantAR system successfully demonstrates the potential of AR and AI in enhancing indoor environments through plant integration. By addressing the identified limitations and continuously improving the user experience, PlantAR can become an indispensable tool for individuals seeking to improve their indoor spaces in a meaningful and sustainable way.

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