FACULTY OF COMPUTING AND INFORMATION TECHNOLOGY

Assignment

BAIT2123 Internet of Things

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Smart Adaptive Display Panel

Description of System

Our IoT system integrates a variety of sensors including brightness, humidity, temperature, motion and Near Field Communication (NFC) sensors to create a smart, adaptive and fully automated environment. Tailored for business professionals, the system serves as a dynamic advertising platform that intelligently adapts to real-time conditions. At its core is an advertising module linked to a digital display that seamlessly cycles through promotional posters uploaded by administrators via an intuitive user interface.

The system also features an entrance guard function, making it suitable for venues such as apartment lobbies, where commercials can reach a wider audience. By continuously analyzing sensor data, the system not only delivers relevant content but also generates actionable reports that support strategic decision-making and improve operational efficiency.

Objective

The objective of Smart Adaptive Display Panel is to build an intelligent and multifunctional panel integrated with an NFC-based gate control system. It can be efficiently used as an advertising platform for business people to advertise their products and services when being offered with adaptive and communicative functionalities such as auto adjustment on brightness, message updating on temperature changes, gesture interaction and so on.

In order to adapt and suit with different environments and scenarios, it also comes with an NFC-Based gate control system which can control the gate opening and closing via recognizing and authenticating the NFC card of different users. This can effectively improve the suitability of Smart Adaptive Display Panel in scenarios like shopping mall entrance and apartment entrance. Not only that, this can also maximize the exposure of business people's product and services advertisement to potential customers.

For achieving this goal, The Raspberry Pi 4 and NodeMCU ESP32 will act as crucial components for implementing all the functions via integrating with different sensors and actuators:

- Display Panel Brightness Adjustment
  - Manual: The system allows users to manually adjust the brightness of the display panel via interacting with web applications.
  - Automation: The system can real-time collect the light intensity information from the light intensity sensor to automatically adjust the brightness on the display panel.
- Temperature Based Message Updation
  - The system will real-time collect the humidity and temperature information from the DHT11 sensor and decide or switch the messages shown on the OLED display panel based on preset messages for different levels of humidity and temperature in Google Firebase.
- Poster Switching via Gesture Interaction
  - The system will use the ultrasonic sensors to sense the obstacle (users' hands) and analyze the users' gesture to identify whether the gesture is swipe left or right.

    - If swiping left, the display panel will switch the poster to the previous poster page and vice versa.
- NFC-Based Access Control
    - The system allows users to use NFC cards to tap on the NFC reader for identity authentication. If the user data in an NFC card has matched the collected data stored in Google Firebase, it will automatically trigger the gate opening and allow the user to pass the gate.
- Time-Based Poster Switching
    - The system will real-time identify the current time every day and switch posters automatically based on different time ranges.
- Real-time Status Updation
    - The system always updates the latest status of the display panel on the web application dashboard interface via retrieving the data detected by different sensors and uploaded in Google Firebase and displays them on the web application dashboard interface for effective status monitoring.
- Daily Report
    - The system will collect information about the number of people who stay in front of specific posters for a longer time at every time slot every day via integrating with ultrasonic sensors.
    - The system allows users to assess the effectiveness of specified advertisement posters via accessing the report of people who have a long staying duration in the web application dashboard.

Business Value

The Smart Adaptive Display Panel is not just a tool which only serves for "displaying something on the screen", but it also implements and combines different valuable features and interactions which are ideal and applicable in different scenarios. It combines a lot of sensing features such as temperature, humidity, gesture, distance and light intensity sensing and utilizes the information gathered to help users to smartly make decisions for immediate execution on the display panel. This has effectively eliminated the human resources for adjusting the display panel settings from time to time such as switching display brightness and poster in different time frames. Meanwhile, it also provides a lot of customizable features for users with different use cases such as manually adjusting brightness, poster switching intervals, posters shown in different time frames, power control on display panel and other relevant features. So, they can easily choose their own preferences for the display panel behaviors. Besides, it can also act as an assessment tool for assessing the performance and effectiveness of posters via identifying the number of people staying. This can significantly help business people to understand which posters should be displayed to attract more customers and increase the frequency of showing those posters.

Besides, the Smart Adaptive Display Panel has also integrated with NFC-based access control. It can scan the NFC card of the people who want to enter and authenticate the identity before opening the gate. Once the authentication is successful, it will control the gate to open allowing users to enter the building. This can effectively decrease the need for manual gatekeepers for manually checking the presence of people and opening and closing the gate. From the aspect of cost, it can also eliminate the cost needed for deploying the non-smart or smart gate. This is because the Smart Adaptive Display Panel has integrated with the gate components as a 2-in-1 cost-effective solution for any place which needs advertisement and gate keeping. Due to the expansion of the features provided, the Smart Adaptive Display Panel can be further applied in more scenarios and environments such as office buildings, school buildings and apartment buildings.

Targeted Users

Business Owners

One of the main targeted users is business owners. There are many business owners operating their business in retail, shopping malls and customer-facing venues. Thus, this will be an excellent opportunity for the Smart Adaptive Display Panel to be applied. It can act as a dynamic advertising platform for intelligently displaying promotional content based on environment conditions, time and user interaction. Meanwhile, the passerby or potential customers can use gestures to realize the poster switching. These interactive features can effectively increase the interest of users for accessing the posters. Sometimes, the business owners may not be able to clearly identify whether the posters displayed can catch customers' eyes if only showing the advertisement posters on the display panel. So, the Smart Adaptive Display Panel can be applied to assess the attractiveness of displayed posters via identifying the number of people staying in front of specified posters for a longer time. In order to help business owners to advertise their products and services to customers in a more comfortable way, the Smart Adaptive Display Panel can automatically adjust the display brightness based on current light intensity and switch the messages shown on an OLED display based on current temperature and humidity. These can provide a more comfortable experience to customers in terms of physiology and psychology.

Apartment and Workplace Management Teams

Most of the management teams responsible for apartments, offices and institutional buildings will possess a security system and announcement board separately. However, they are not able to smartly communicate with each other while causing a high cost. Thus, Smart Adaptive Display Panel can be leveraged for their needs to combine both security system and announcement boards with communication functionality. The NFC-based access control can be used to authenticate the identity of students, staff or residents before opening the gate for entrance. Once they are authenticated, it will open and close the gate automatically. Meanwhile, the display panel can be used for showing important announcements dynamically to the people who are going to enter. These two features can collaborate with each other to allow people to take notice of announcements or notices when waiting for passing the gate. These can effectively ensure the building's security while offering useful notices and announcements to users.

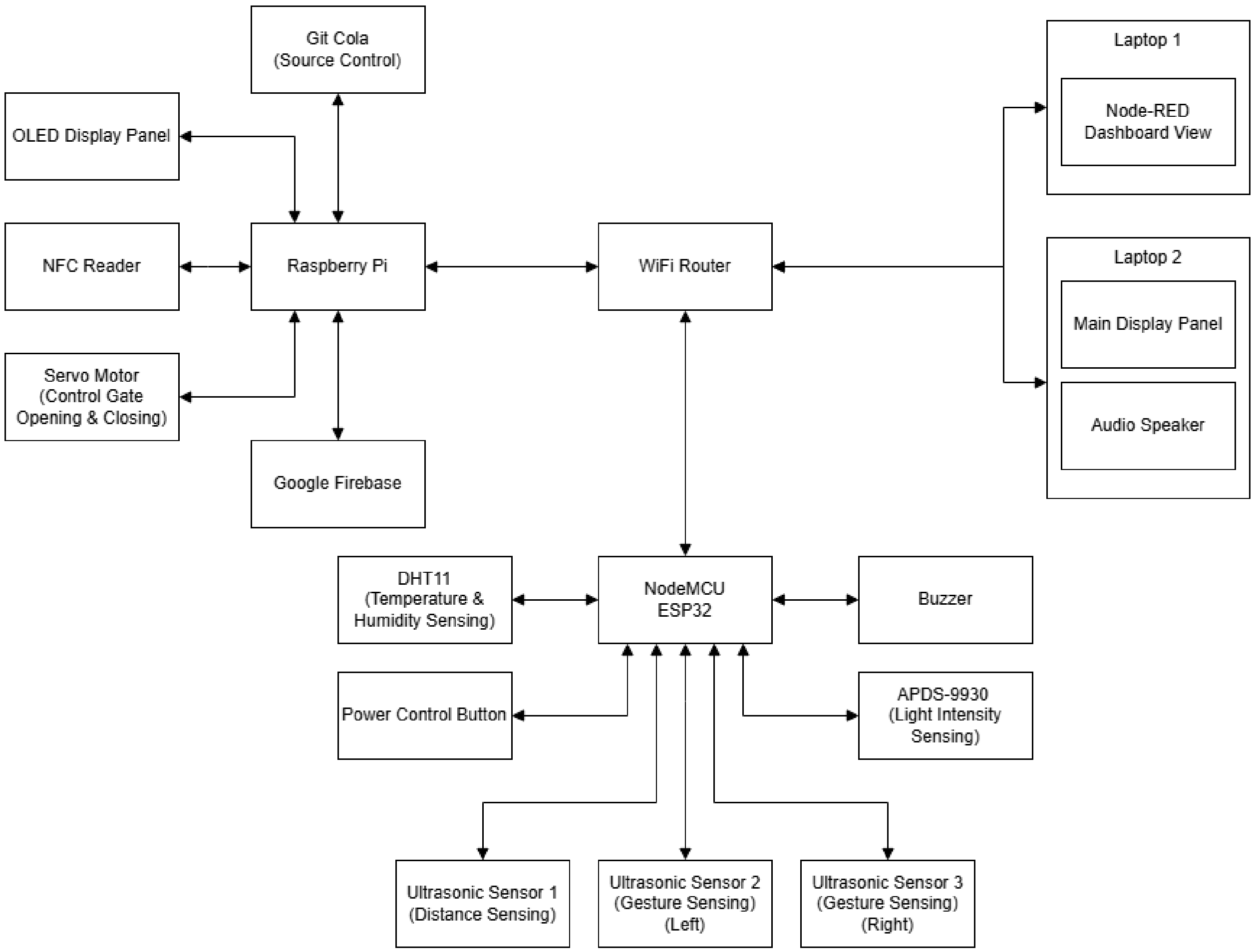
System Design

Reference System

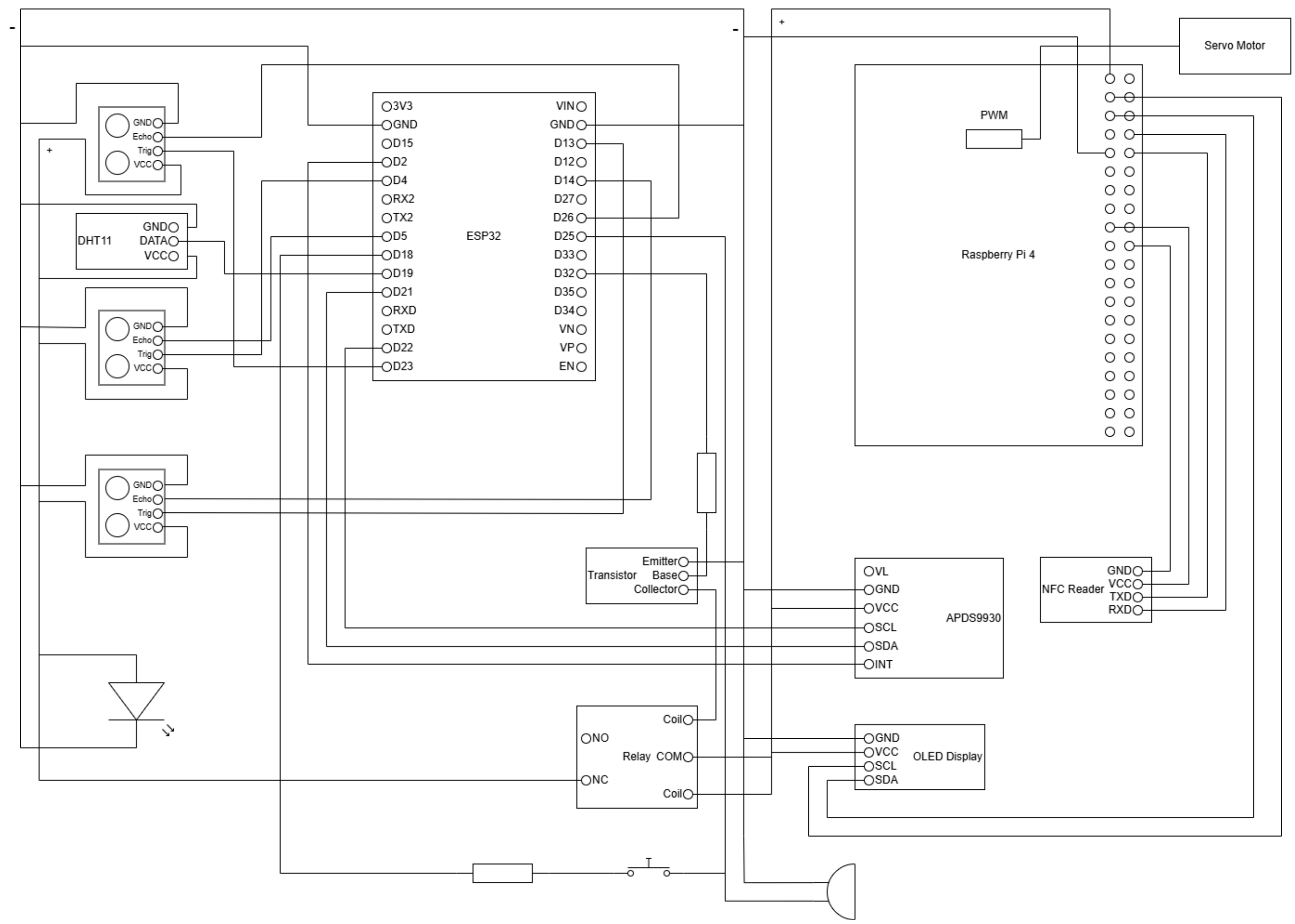
Nowadays, there are a lot of shopping malls where various digital advertising panels are being installed in such as Sunway Pyramid, One Utama and Mid Valley Megamall. However, it is found that most of the advertising panels do not have interaction functionalities. They can only repeatedly loop the specified series of posters without customizable settings and interaction from users in the mall. There is also a limited time for users to read the poster as the poster display always loops in a certain specific time interval. Users are not able to stop the poster switching when they only want to read a specific poster only, they can only wait for the next loop of posters so that they can read the poster. Meanwhile, the digital advertising panels do not have built in light intensity sensors for adjusting the display brightness to adapt to the environment changes. When the brightness of the display panel is too bright, it will cause a burden to users' eyes to read the posters clearly. When the brightness is too dark, the effectiveness of the advertising board will be dropped significantly as users hardly or can't even see the clear posters. Thus, we have obtained the inspiration from these problems stated and decided to build a smart adaptive display panel which can solve these problems via integrating the display panel with sensor data processing and response.

We also drew inspiration from NFC-based entry systems commonly used in apartments. These systems provide secure automated entrances for residents, but are independent of advertising or messaging functions. Based on this, we designed an intelligent adaptive display panel that integrates digital advertising and entrance control functions. Ideally suited for high-traffic environments such as shopping centers, apartment lobbies, office buildings, and institutional entrances, it is a single smart solution that is both engaging and efficient.

IoT Solution Architecture



Schematic Diagram



Modules Description

Sensor Data Acquisition Module

Sensor data acquisition module mainly focuses on integrating different sensors to collect data and transfer the data to collaborating devices. Thus, the web application is able to obtain the latest status information of the display panel and update on the dashboard interface. Meanwhile, this module also helps for obtaining data from NFC cards or tags for authenticating users.

- Sensing light intensity at surrounding
- Sensing temperature at surrounding
- Sensing humidity at surrounding
- Sensing gesture or obstacle in front of the display panel
- Apply MQTT for sending requests and retrieving responses from collaborating devices
- Update sensor information in Google Firebase

Device Control Module

Device control module is responsible for managing the operational status of key hardware components, including sensors and display monitor. It provides a centralized control over the power supply and display behavior through both physical buttons and the web application interface. It ensures a seamless communication between devices using MQTT when allowing real-time remote control and automation.

- Sensors power control via button and web application
- Monitor display power control via MQTT
- Accept brightness adjustment MQTT requests and adjust the display panel brightness

Guarded Entrance Hardware Module

The Hardware module directly interacts with the physical components: the NFC reader, servo motor, and buzzer. It performs low-level actions such as scanning for card presence, opening the gate, or sounding feedback tones, based on instructions received from the processing module.

- Continuously scan for NFC card presence in read mode
- Perform card read and write operations when instructed
- Open the gate via servo motor upon successful verification
- Activate buzzer with long or short beeps based on access outcome
- Expose functions to the processing module for use in logical flows

Sensor Data Processing Module

Sensor data processing module mainly focuses on interpreting and deducing the appropriate adjustment upon environmental and user-interaction data collected by the system's sensors. This module ensures the display panel responds intelligently to real-world conditions, providing a personalized and adaptive user experience.

- Analyze brightness data at surrounding
- Analyze humidity data at surrounding

- Analyze temperature data at surrounding
- Collect the data of people close to the display panel
- Updates and retrieves data from Google Firebase
- Switches message display based on sensor data
- Track distance and gesture interactions obtained from MQTT to navigate posters and identify the most viewed poster for the time period (upload poster ID to Firebase)

Advertising Module

Advertising Module manages the presentation of posters on the display panel. It provides a dynamic and interactive platform for delivering full-screen advertisements with visual and audio elements, tailored to the time of day, environment and user interaction.

- Full screen poster display (Chromium) and audio autoplay
- Swipe poster based on gesture received from MQTT
- Poster switching, auto loop poster based on interval set at UI
- Adjust display panel brightness based in sensor data analyzed
- Switching oled display content based on the message that return from the sensor process

Guarded Entrance Process Module

The Processing module acts as the decision-making core that handles logic between UI commands and hardware operations. It interprets MQTT messages from the UI and executes appropriate actions, such as checking UID validity in Firebase or triggering hardware behaviors. It ensures system access rules are followed before allowing entrance or exit.

- Analyze incoming UI commands (read, write, verify UID)
- Check scanned card UID against Firebase records
- Update Firebase with new or modified UID and resident information
- Decide whether to grant access or deny entry
- Trigger the hardware module to control the motor or buzzer

User Interface Module

The User Interface module is the central management point for system configuration and operational control. It allows administrators to configure runtime settings, manage content, and monitor device status in real time. This module does not directly handle sensor processing or visual displays, but instead provides structured control and input for all other modules.

- Manage poster records for each time slot (create, update, delete)
- Manually set display brightness or switch to auto-brightness mode
- Define OLED display message rules for different environmental conditions
- Display power control toggle that sends MQTT commands to hardware
- View real-time sensor status and updates synchronized from Firebase

Guarded Entrance UI Module

The User Interface module provides access control management through simple visual controls. It enables administrators to register new users, initiate card writing operations, and monitor entrance activity. The UI does not perform validation or access checks but sends corresponding MQTT commands to trigger operations in other modules.

- Trigger card write or read mode for registration or scanning
- Display scan results and access status received from Firebase
- Send user data to Firebase for UID registration or updates
- Allow administrators to remove or update registered UID records
- Monitor real-time entrance status and NFC scan activity

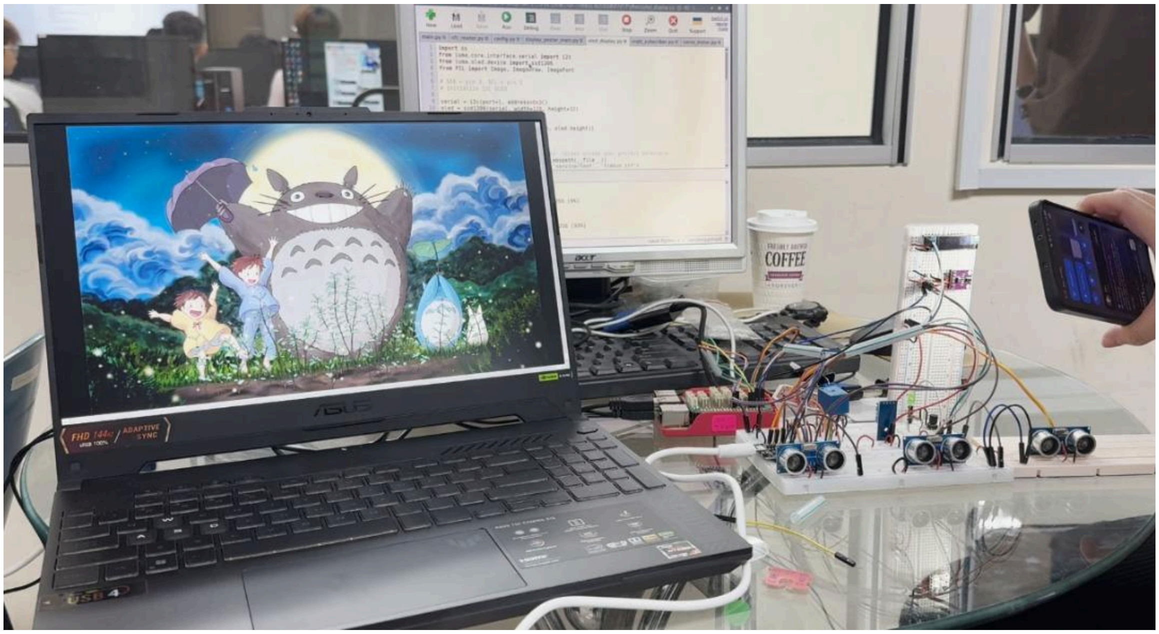
Report Module

The Reporting module allows administrators to select a specific date range and time slot to analyze poster participation over time. It processes historical interaction data stored in Firebase and generates daily, monthly or yearly reports based on the selected range. The focus is on calculating how many users showed up during a given time period and which poster users stayed on the longest.

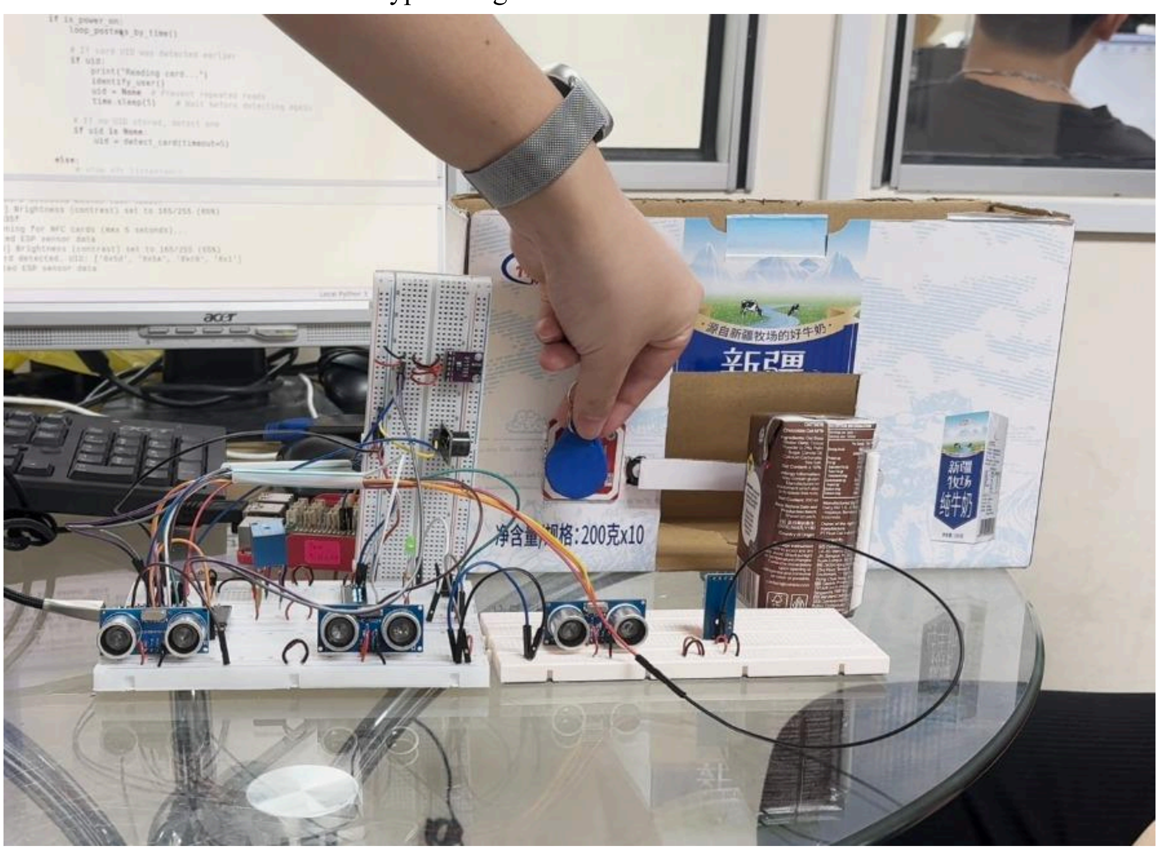
- Accepts administrator input: start date, end date, and time period
- Retrieves and summarizes report data from Firebase for the selected time period within the selected date range
- Group and calculate the totalPeople who interacted with the display panel during the selected time period
- Sum the frequency with which each poster was the longest-staying poster during the selected time period
- Automatically determine the report type based on the length of the date range (daily, monthly, yearly)

Snapshot / Picture of prototype design

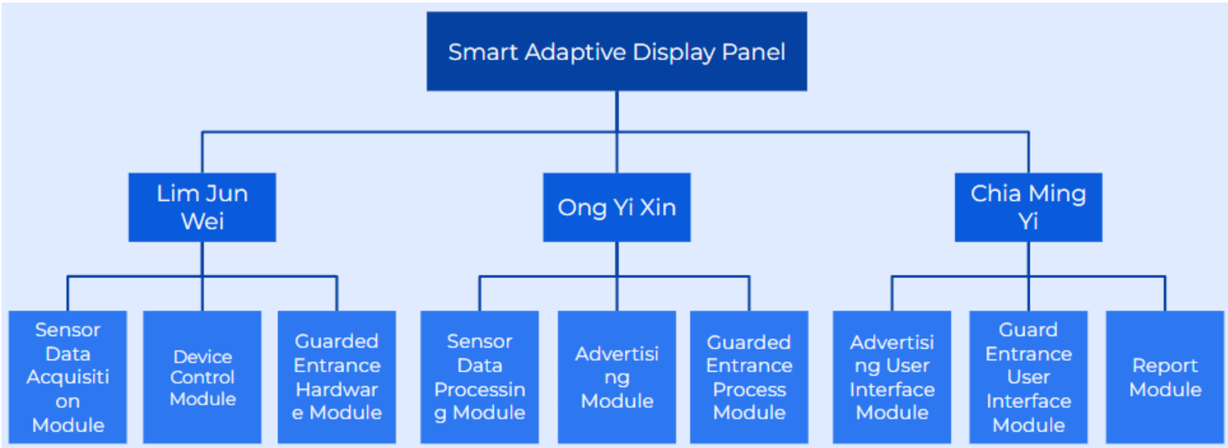
Advertising Module Prototype Design



Guarded Entrance Module Prototype Design



Task Allocations



Lesson Learned / Problem Faced

Problems Faced

Gesture Sensing Issues

Problem	The APDS-9960 gesture sensor malfunctioned during developing phases due to damage or internal component failure. Thus, the gesture-based interaction for switching poster display was no longer functional.
Impact	The loss of gesture sensing has seriously affected the planned user experience. Users will not be able to switch the poster to the previous or next poster via gesture "swiping from left to right" and "swiping from right to left".
Solution	In order to overcome this limitation, two ultrasonic sensors were used as a substitute to detect hand proximity or presence in front of the panel. The distance or proximity data sensed by two ultrasonic sensors will be analyzed and converted into directional gestures information. Via this method, gestures of swiping left and right can be successfully detected when the user is near. Thus, the feature of switching to the previous or next poster can be worked properly.

Source Control Problems

Problem	The Raspberry Pi and SD card used for development are university-owned and cannot be taken home. This restriction made it difficult to continue development or update the latest code outside of campus hours. Team members often worked on code at home without being able to test or deploy directly on the device.
Impact	This limitation caused version mismatches and delayed integration. Team collaboration became inefficient, with code updates being shared manually or delayed until access to the Raspberry Pi was available on campus. It also increased the risk of overwriting or losing updates.
Solution	To resolve this, the team adopted Git Cola, a graphical Git client, to manage version control. A central Git repository was created to allow all members to push, pull, and synchronize code remotely. This ensured that everyone always had access to the latest code version. Meanwhile, conflicts could be resolved early before testing on the Raspberry Pi. Thus, collaboration became more structured, improving workflow efficiency.

Power Supply Limitations

Problem	Due to the power supply limitation in Raspberry Pi and ESP32, the sound speaker is not able to be installed on them for playing the audio during poster displaying. Meanwhile, the ESP32 is not able to provide enough power to the various sensors.
Impact	It has led to the problem of speakers and sensors not functioning.
Solution	For the issue of sound speakers, the built-in speaker in the laptop (display panel) will be used to replace the sound playing feature on the external speaker. This can effectively

	reduce the workload of Raspberry Pi while ensuring the successful audio playing. Meanwhile, the power of sensors such as DHT11 and ultrasonic sensors will be supplied by Raspberry Pi 3.3V instead of directly using ESP32 to supply the 3.3V. This can promise a more stable electric current while reducing the workload of ESP32.

Image and Audio Handling

Problem	The display panel will require a series of poster images and audio files for displaying posters on the display panel screen and playing the linked music. However, there is limited Google Firebase storage (free version), so storing the entire images and audio files will be an impractical action.
Impact	This will significantly affect the basic and fundamental operation of the display panel for showing the required posters and playing the background music.
Solution	In order to handle all the images and audio file uploading, A free API IMGBB was used to convert all the image files and audio files into the url. Thus, only the image and audio URL are needed to be stored into the Google Firebase, efficiently optimizing the limited storage used in Google Firebase. As a result, all the images and audios can be played on the display panel successfully via retrieving and running the stored URL.

Firebase Sensor Data Updating

Problem	In expectation, the ESP32 will upload the sensor data into Google Firebase after gathering the sensor data successfully. Then, the Raspberry Pi will collect the latest data from Google Firebase for analyzing and responding with appropriate action. However, there is a huge delay from sensor data uploading from ESP32 to Raspberry Pi retrieving sensor data from Google Firebase since ESP32 can only support 2.4Ghz Wi-Fi connection which is slow.
Impact	It will take a very long time for Raspberry Pi to obtain the latest data and generate responses on the display panel and send MQTT replies.
Solution	In order to minimize the delays between ESP32 and Raspberry Pi to upload and retrieve sensor data, ESP32 will send the sensor data to Raspberry Pi using MQTT and let the Raspberry Pi upload the latest sensor data to Google Firebase. This is because the Raspberry Pi is directly connected to the router via LAN cable so it will have faster connection speed. As a result, the delay can be minimized effectively to ensure an acceptable user experience.

Language Support on OLED Display

Problem	The OLED display initially did not support Chinese characters when attempting to display multi-language messages such as temperature and humidity messages. The default font library was unable to display non-Latin characters, especially Chinese text.
Impact	As a result, temperature and humidity information containing Chinese characters is either displayed incorrectly or not displayed at all. This results in an incomplete or confusing

	advertising module, especially for Chinese-speaking users, and reduces the overall clarity and usability of the display.
Solution	To resolve this, the SimSum.ttf font, compatible with Chinese characters, was integrated into the OLED rendering process. This font enabled proper rendering of Chinese text, allowing temperature and humidity messages to be displayed accurately and clearly in Chinese on the OLED screen.

MQTT Transmission Clashing in Node-RED

Problem	MQTT transmission may clash when a single UI node handles multiple topics directly, leading to incorrect processing or data routing.
Impact	These clashes can cause the wrong data to be displayed or sent, trigger unexpected UI behavior, and significantly complicate debugging.
Solution	Use function nodes to route messages based on topics using if-else or switch logic. Separate input and output handling for each topic, and maintain a consistent message structure with clear identifiers.

Full-Screen Viewing on Laptop Screen

Problem	The default browser does not automatically launch the poster display in full-screen mode. The standard browser interface, including the tab bar and address bar, is still visible and interferes with the immersive display effect
Impact	This limitation affects the quality of the poster presentation, as some of the poster content may be obscured by the browser's user interface elements. This negatively impacts user satisfaction and reduces the visual impact of poster presentations.
Solution	To solve this problem, we used a Chromium browser with a specific startup logo that enabled a kiosk-style full-screen mode. This approach removes the browser's user interface elements and allows the poster to be displayed full-screen without interruption, thus improving the visualization and user experience.

Audio Playing Together with Poster on Display Panel

Problem	Both standard browsers and Chromium impose autoplay restrictions on audio playback, requiring user interaction before any sound can be played, especially in looping mode. However, in our module, there is no direct interaction between the user and the browser, so it is not possible to autoplay audio when displaying a poster.
Impact	This limitation impacted the integrity of our presentation module by displaying the poster without playing the associated audio. The lack of synchronized audio diminishes the immersive and informative experience that users expect.
Solution	To overcome this, we integrated the Python pygame library to play audio directly from the

	provided URL. This method allows the system to stream and play the audio in sync with the poster display without requiring prior download or user interaction, restoring the full multimedia experience as designed.

Conclusion

The Smart Adaptive Display Panel is an IoT-based advertising system designed to intelligently adjust content based on environmental conditions and user interaction. Developed using a Raspberry Pi 4 and ESP32, the system integrates brightness, temperature, humidity, motion, ultrasound and NFC sensors to increase its responsiveness and versatility. Posters are displayed in predefined time slots and each poster is accompanied by audio that plays automatically during the display.

Gesture control is enabled by two ultrasonic sensors, allowing users to navigate between posters with hand movements, creating a contactless interactive experience.The NFC module adds secure access control, allowing users to authenticate themselves at gated entrances, ideal for environments such as apartment lobbies or office buildings. All sensor readings and user interactions are updated in real-time to Firebase, allowing administrators to monitor the data and generate performance reports through a web interface, making the system an intelligent, interactive, data-driven advertising and access control solution.