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Software Engineering for Developing a Cloud Computing Museum-Guide System

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ABSTRACT

The aim of this article proposes an innovative solution for developing a museum-guide system, which employs a voice-activated assistant paired with 3-D hologram displays, that utilizes Amazon web services (AWS) to enhance the visitor experience at the Bahrain National Museum. The proposed system uses software engineering as a service (SaaS) and involves an agile development process model with microservice architecture that adapts cloud computing capabilities to provide scalability, reliability, and maintainability. The proposed system enhances the existing museum infrastructure and databases through a flexible, API-based architecture. The proposed system is highly adaptable and flexible in different desirable aspects of user experience goals. The implementation results proved that the system is highly reliable, adaptable, and efficient and has the potential to improve the user experience by transforming the way museum visitors explore and interact with user interfaces of the museum-guide system.

KEYWORDS

Agile process model, Cloud Computing, Human-Computer Interaction, Museum-Guide System, Software Engineering, User- experience

INTRODUCTION

In recent years, the use of technology in the museum industry has been increasing rapidly. From digital displays to Virtual Reality (VR) experiences, museums continuously explore new ways to enhance visitors' experience and provide more engaging and interactive exhibits (Kasemsarn et al., 2023). However, despite these advancements, one area that remains essentially unchanged is providing information for visitors. Traditional methods, such as tour guides or information boards, can be time-consuming and ineffective, causing a subpar experience for visitors. In this respect, visitor experience represents a critical component in the success of the museum operations. Providing positive and informative experiences is increasingly important for visitors in today's competitive museum landscape. Thus, an intelligent tourist guide system is vital for enhancing self-guided tours

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and improving tourists' experience during their tour (Yu, 2014). This paper proposes a tour voice-activated assistant, paired with 3-D hologram displays, that utilizes Amazon Web Services (AWS) to enhance visitor experience at the National Museum of Bahrain. It identifies the challenges the museum encounters in providing information for visitors and evaluating the effectiveness of the developed solution for addressing these challenges. Bahrain National Museum is well-known for its rich collection of artifacts and exhibits. However, the Museum faces several challenges in providing an efficient and informative experience for visitors, which often requires additional support in the form of tour guides, and the manual counting process is time-consuming and prone to errors (Jung et al., 2016). The proposed museum-guide system aims to address these challenges by automating the counting process and providing employees with real-time data and predictions for incoming traffic. Additionally, the tour voice assistant with 3-D hologram displays provides visitors with accurate and timely information without additional tour guides.

Software engineering as a service (SaaS) enables the proposed system to adapt the Agile development process model based on a cloud computing environment with AWS services. The proposed solution is also highly adaptable, making it easy to implement in other locations. The proposed museum–guide system, which leverages software engineering development, uses an agile process model and employs a microservice architecture to optimize scalability, reliability, and maintainability. In this system, 3-D holographic displays are a standout feature aiming at transforming user's interaction with museum artifacts. This results in high reliability and adaptability of the system, indicating its potential to improve the user experience. Implementing 3-D holographic displays is an innovative feature to transform and enhance user interaction with museum artifacts. More specifically, these displays allow museum objects and augmented reality (AR) reconstructions related to the artifacts to be viewed by visitors in an immersive and interactive holographic format. This emerging technology aims to provide museum patrons with a vivid, lifelike experience when learning about historical items. The adoption of AWS serverless architectures achieves scalability, resiliency, and efficiency. The system can automatically scale capacity based on demand by utilizing services such as AWS Lambda, Amazon API Gateway, and Amazon DynamoDB in a serverless framework, while only paying for the computing resources used. The service-oriented nature of the museum-guide system presents serverless technology that empowers rapid delivery of critical functionalities to improve the user experience while decreasing operational burdens.

The proposed system provides audio descriptions and text-to-speech options for visually impaired visitors. This system involves describing the exhibit or providing audio guides verbally explaining the contents. Additionally, it supports hearing impairments by including closed captioning or subtitles for any audio content within the AR system. This support ensures that visitors with hearing impairments can understand the information being presented. The proposed system is highly adaptable and flexible. Incorporating features for visually or hearing-impaired users could significantly broaden the system's appeal and utility and enable it to cater to the needs of a diverse range of visitors, including children, seniors, and visitors with disabilities. For the Museum of Bahrain, the proposed system designs a well-architected, scalable, and flexible AWS framework that can adapt to evolving business needs. Using an Agile development methodology and a microservice architecture, along with AWS serverless services, enables the system to be reliable, efficient, and readily scalable. Such an approach allows easy modification and upgrading of the system, ensuring that it can meet the needs of the Museum both now and in the future.

LITERATURE REVIEW

A museum is an institution that represents heritage, cultural, and artistic treasures for centuries. However, with new technologies and the ever-changing visitor requirements, museums are expected to evolve to remain relevant and engaging. A study by Kasemsarn et al. (2023) used a systematic literature review and reviewed the interrelationship between cultural tourism, inclusive design, and digital storytelling. They present an initial framework for cultural tourism through inclusive digital storytelling, exploring, and reviewing the relationship of three key areas identified. It examines the impact of digital storytelling, 3-D technology, virtual accessibility, offering different languages, and creating new visitor experiences to improve their understanding and motivations. Also, the study underscores the importance of managing resources, effective communication, and shaping visitor experiences using inclusive design and digital storytelling. In another study by Cappaert and Redei (2020), they developed a system that employs a cloud-native solution and a scalable Django application in conjunction with Heroku and Postgres. This integration has created an innovative platform for tracking museum activity and persisting user data. The system shows potential for enhancing the museum experience through interactive activities and a leaderboard system. However, there are several limitations and areas for improvement to consider. One limitation is the reliance on QR codes for registration and interaction, which may pose usability challenges for some users, and the need for additional options for registration and interaction. In addition, the system's effectiveness may be limited by the rules and restrictions of specific museums, which reduce the value and novelty of the interactive activities. Another limitation arises from the system's setup and management due to its requirement of significant effort and resources from the museum administration, potentially limiting scalability and feasibility. Under such circumstances, it is important to carefully consider the system's usability, effectiveness, and scalability implications.

A context-aware museum guide for visitors' specific exhibit information needs was presented by Vahdat et al. (2018). The study provides additional features to improve the system's effectiveness including visit planning and direction, location, facilities, and services. Regarding designing the system architecture, the Attribute-Driven Design (ADD) method is employed to identify and model system attributes that are highly adaptable, easy to maintain, and satisfy the users' needs for high usability and modifiability. The system comprises a mobile component, divided into data and decision trees, and a cloud-based server component. The system comprises Near-Filed communication (NFC) tags, a cloud let server, and a wireless network to provide visitors with a seamless museum experience. The proposed system has several benefits, such as providing visitors with personalized information on exhibits and directing them through the museum. However, the system has a limited scope, focusing primarily on specific aspects of the museum experience while neglecting others, such as social interaction, engagement with staff, and serendipitous exploration. Hanussek (2020) discusses using a mobile-based application that provides information about the institution, exhibition-related content, location aids, audio guides, 3-D models of objects, and personalization features. In addition to interactive games and activities, Custom-developed Apps may not be reusable or transferable to other sites or institutions. Additionally, visitors may not be willing to download a dedicated App or create an account on a website to access information about a museum or other cultural institution.

Personal tour guide systems have also been studied, such as Singh and Singh (2015), who investigated a personal tour guide system for displaying multimedia information based on user location. When tourists approach an attraction, they are notified, and the relevant multimedia file is played on their Android-based mobile devices. The system can execute the application in standalone mode without connecting to the web or relying on telecom networks. Similarly, a study by Jeon et al. (2014) conducted at the Lee Ungno Museum in South Korea developed sound tags to allocate each artistic exhibit. These tags periodically disseminate the unique ID information of each artistic exhibit in the environment through audible audio signals. The microphone on each visitor's mobile phone automatically detects the signal from the closest sound tag and plays the relevant audio file for the visitor. In addition, Chih et al. (2010) developed a location-aware tour guide system that combines wireless networking. The system establishes content in digital archives for museums along with interior locating technology and geographical information systems.

This paper makes several key contributions to the literature on interactive museum-guide systems. The proposed solution uniquely integrates natural language processing (NLP), 3-D holographic, voice control, and cloud infrastructure to facilitate an accessible and engaging museum visitor experience.

The proposed solution develops a system of visual and conversational interfaces via 3-D holographic projection and conversational AI services. The hands-free voice interaction facilitated by Amazon Lex integration offers visitors an intuitive means to explore exhibits. Amazon Lex powers the voice interaction capabilities of Alexa, Amazon's popular virtual assistant technology. Alexa is used in various hands-free, voice-controlled devices and services, enabling more natural and convenient interactions in many use cases. By leveraging Alexa and Amazon Lex, museums can create innovative exhibit exploration experiences that allow visitors to obtain information simply by asking aloud in natural language (NL). Voice control promotes accessibility and seamless learning during museum visits. This natural mode of inquiry assisted by machine learning represents an advancement over text or touch-based methods relied upon in earlier museum guides (Vahdat et al., 2018).

While previous exhibits have experimented with augmented reality and other display methods (Jung et al., 2016), this research pioneers using sophisticated 3-D holographic visualization powered by cloud computing resources. By leveraging advanced 3-D scanning and rendering techniques facilitated through cloud services, the system projects strikingly realistic representations of artifacts—an unprecedented capability for visitor engagement. Critically, the proposed solution aims for broad accessibility through its choice of input and output channels. For example, the speech-based interface provides accessibility to vision-impaired visitors often excluded from museum technologies centered around visual displays. In addition, the projection-based interface bypasses the need for visitors to manipulate a device and enables participation across age groups and abilities. Thus, this research proposes an innovative integration of conversational artificial intelligence, 3-D holographic projection, and cloud-based infrastructure to facilitate engaging and accessible museum exhibits.

The proposed system has several advantages. Leveraging Amazon Web Services (AWS) for cloud-computing infrastructure ensures high security. Specifically, AWS provides capabilities such as identity and access management (IAM) AWS services, encryption, vulnerability scanning, DDoS mitigation, and advanced threat detection to safeguard the museum-guide system and data. The AWS platform allows developers to scale the security measures appropriately as usage grows. The museum-guide system enhances previous museum guides by enabling natural voice-based interaction for visitors to intuitively explore artifacts. Sophisticated 3-D rendering techniques realized via cloud computing services, the solution pioneers strikingly realistic visual representations of historical objects—a capacity thus far unseen in interactive guides. Most critically, by emphasizing speech and hands-free holographic interfaces, the system promotes participation for those with visual, mobility, or other challenges often marginalized in conventional exhibit technologies. Thus, in contrast to prevailing text, image, and device-based approaches, the present solution offers museums a radically more immersive, usable, and inclusive platform for visitor self-guidance. By comprehensively addressing the limitations of existing systems across multiple dimensions from interactivity to accessibility, this innovative research carries profound implications for reimagining the future museum experience. Moreover, the system's one-time deployment process and absence of additional hardware or software make it highly convenient and easy to implement in various locations. Also, it provides a significant advantage over the existing systems. The proposed system demonstrates significant potential in addressing the informational needs of visitors and offers accessibility and inclusivity for a broad range of users.

SOFTWARE ENGINEERING PROCESS MODEL

The proposed museum-guide system uses an Agile development process model methodology, explicitly incorporating elements of Scrum and Lean processes (Rasnacis & Berzisa, 2017). The agile method emphasizes iterative delivery of working software, customer collaboration, and responding to change. The sprint-based approach enabled rapid development, testing, and refinement cycles (de la Harpe & Sevenhuysthe, 2020). Figure 1 illustrates the initial sprints focused on requirements gathering, prototyping, and architecting the overall system structure. Adopting Agile principles, the architecture and components were designed to be modular and decoupled (Razzaq, 2020), facilitating incremental development and testing of individual components before integration. Frequent integration sprints then allowed for end-to-end testing and identifying areas for optimization (Younas et al., 2016).

The Agile development methodology is crucial to deal with uncertainties inherent in integrating diverse emerging technologies into an integrated system. Specifically, the lack of accessibility to holographic projection equipment causes difficulties in the development and testing of the system, whereas the sprint-based approach provides flexibility to work around such constraints and make progress on other components. The cutting-edge nature of leveraging Amazon Lex v2, before extensive documentation or all features were fully productized, led to discoveries mid-development requiring changes in the approach.

Integration with the existing systems also poses challenges, such as how the limited initial access to museum databases and content management systems could hamper efforts to build capabilities dependent on that connectivity. However, despite external dependencies, progress can be made by focusing on prototyping standalone functionality. The incremental builds and overall proposed system architecture are designed to facilitate the integration of these databases once access is established.

More broadly, transforming the innovative vision into an operational reality involves overcoming technology limitations, especially in speech interfaces. Optimizing components for the Raspberry Pi's performance constraints and working around latency stemming from cloud dependencies will require time-consuming reengineering. Extensive testing surfaced suboptimal user interactivity, while architectural modularity and API-based interfaces enabled continuing enhancement. The combination of Agile sprints and microservice-oriented architecture provides essential agility. The cyclic develop-test process quickly surfaced impediments, while component-based structure isolates the impact of changes. Together, these methodologies enable the pragmatic evolution of the system despite considerable uncertainty and obstacles surrounding this unprecedented fusion of technologies.

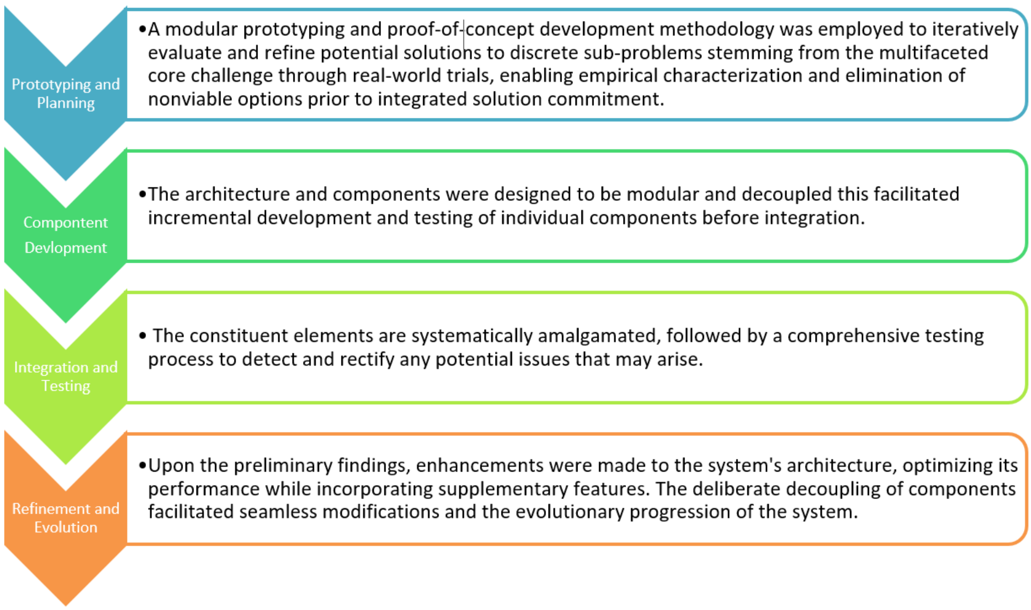
The Agile team adapted approaches sprint-by-sprint, progressively transforming an ambitious concept into functional reality through a deliberately incremental construction process. Throughout the development process, a foundational aspect of the Agile approach is actively engaging museum stakeholders via iterative sprint reviews and planning workshops. After each sprint, hands-on demos and progress updates are provided to curators, administrators, and visitor experience staff. Direct feedback gathering technique has also been used for software functionality, usability, exhibit integration considerations, and opportunities to meet the museum's goals and needs. Plans for the subsequent sprint can be adjusted based on this input. It enables the system design to progressively evolve based on real-world evaluation from domain experts. Within each two- to three-week sprint, a close build-feedback loop encouraged customer-driven prioritization and requirements clarification. The final solution delivers maximum value and fit by sustaining intensive museum participation sprint-over-sprint. The recurring stakeholder input ensures adaptation to changing needs even as the innovative fusion of technologies takes shape through rapid iterations.

PROPOSED SYSTEM ARCHITECTURE

The proposed solution for the Bahrain Museum-Guide system follows a microservice architecture based on the AWS Well-Architected Framework (2022). Figure 2 illustrates the proposed system architecture, comprising loosely coupled components that encapsulate specific functions and communicate via lightweight APIs. This approach aligns with the principles of the Well-Architected Framework, promoting modularity, resilience, and flexibility according to AWS Well-Architected (2022) Framework.

The microservices in Figure 2 encapsulate management, monitoring, and query handling functions. This aligned decomposition into discrete, loosely coupled services aims to achieve the modularity, isolation, and interoperability emphasized as cloud computing best practices by AWS. By segregating components based on functionality, the proposed architecture can enhance fault tolerance,

Figure 1. Execution phases of the proposed framework in agile process model in cloud computing environment

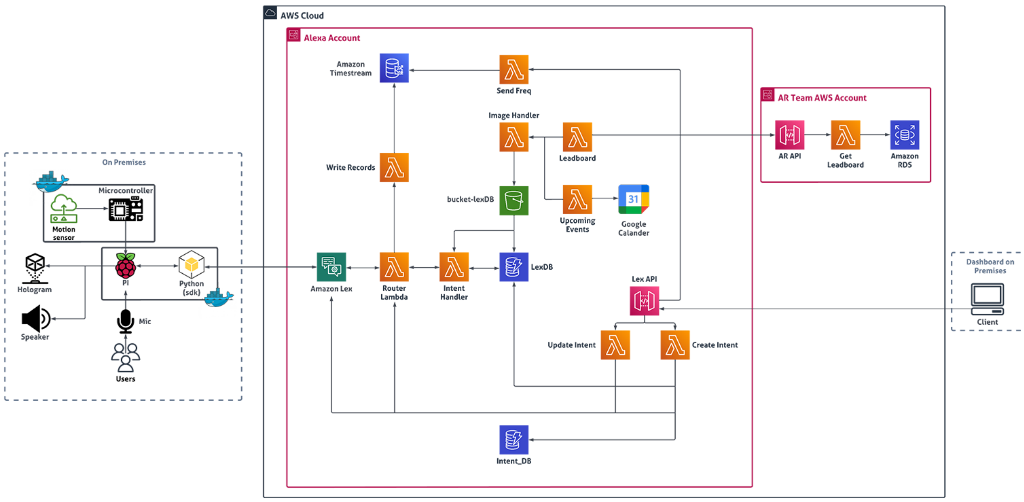


accelerate troubleshooting, and simplify maintenance as individual services with independent modification or replacement.

Unlike monolithic systems, microservices enable the integration of diverse technologies that are optimally appropriate for each task. This integration facilitates employing “best-of-breed” solutions to enrich specific functions like natural language processing (NLP), 3-D graphics rendering, and database functionality, enhancing the overall museum visitor experience. Open protocols like REST APIs and event streams enable interoperability between diverse services. Ultimately, through its cloud-native architectural approach manifesting AWS best practices, the proposed museum-guide system is poised to unlock the profound possibilities of cloud computing for redefining visitor engagement. The fusion of operational excellence, security, reliability, and other traits harbors an environment appropriate for sustaining engaging, personalized services and inclusive user interactions. By thus realizing AWS’s well-architected ideals, the solution can fulfill the expansive promise of continuously adaptive, perpetually refinable, and indefinitely scalable museum exhibits. According to Wang et al. (2014) and Kassab et al. (2015), user stories are the most popular requirements notation in agile projects. A user story is a method of requirements elicitation in the Agile software process model; 90% of Agile practitioners employ user stories to capture these requirements, and 70% follow a simple template when creating user stories (Dalpiaz & Brinkkemper, 2018). The design of the proposed system depends on a set of user stories derived from the primary use cases of a conceptual model. This design then reflects the users’ needs and goals. The microservices are developed and deployed independently, enabling independent scaling and easing maintenance as changes to one service do not directly affect others, and the risk of unintentional side effects is reduced (Razzaq, 2020). To this end, the proposed microservice architecture follows established best practices for creating adaptable and reliable systems. The modular of the proposed solution is designed based on an analysis of end-user needs intended to yield a robust, scalable solution for Bahrain Museum-Guide. The independent deployment capabilities ensure maintainability and facilitate future enhancement.

The conceptual framework for developing the proposed Museum-Guide system comprises the following components:

Figure 2. The conceptual framework of the system architecture



System Hardware Components - A proposed system architecture includes hardware components for controlling, motion detection, and hologram design and improving the system's performance. These components are as follows:

Microcontroller and motion detection - The system utilizes an ESP32 microcontroller with FreeRTOS and UART communication protocols and an HR-SR04 ultrasonic sensor, to provide a cost-effective and replaceable motion detection solution. Docker is integrated for consistent development and testing environments(Deshpande & Liu, 2017).

Rassberry Pi - is the primary computing device due to its affordability, low power consumption, and versatility. To improve the system's performance, over- clocking of the Raspberry Pi was implemented, increasing the processor's clock speed, resulting in faster response time.

Microphone and Sound Capture - The Sarbanes-Oxley (SOX) utility was utilized to capture the sound. The 16-bit resolution, 16000 Hz sample rate, a signed integer data type, and little-endian byte order are the most often sampling frequencies used as the audio formats (*.WAV,*.PCM). Options were included to detect and remove periods of silence from the recording, with a minimum duration of one second and a threshold set at one percent of the maximum audio level. The resultant audio was then stored in a file and sent to AWS Lex for processing, allowing for the effective collection of audio from the microphone for use in the system.

3-D Hologram

Pepper's ghost is a cost-effective technique for creating holographic experiences, which involves reflecting an image onto a partially reflective surface at a 45-degree angle to create the illusion of a floating image viewable from multiple angles. This study used a 43-inch LED TV connected to a Raspberry Pi via HDMI for the hologram. However, the partially reflective surface used in the technique can introduce distortions and reflections, decreasing image quality. Additionally, reducing video resolution and rotating it can result in losing image detail and sharpness. To overcome these limitations, the researchers explored a combination of approaches to find a middle ground that optimizes the holographic experience. They used high-quality, high-resolution videos and advanced compression techniques to minimize image quality loss while still being able to be rotated and scaled to the proper perspective. They also used a partially reflective surface with reasonably high reflectivity and low distortion to reduce the impact of reflections and distortions. Optimal studio lighting and controlled viewing conditions gave users optimal viewing angles and minimized ambient light interference. The resulting videos incorporate the integration of AR features for supporting people with hearing impairments to see sign language translations of the artifact's description narrative.

System Software Components

The proposed system used the software components for designing the user interface, allowing the system to monitor sensors concurrently, perform hot-word detection, and respond to user inputs without delays or interruptions. These components are as follows:

Python SDK - The Raspberry Pi was programmed using Python SDK, which is broadly used in the industry for its ease of use and the vast library of modules. A pre-trained model for hot-word detection was utilized, allowing the system to accurately detect specific keywords and phrases the user speaks. The system is containerized using Docker, which enables easy deployment and scalability. Threads were used to ensure a seam-less user experience, allowing the system to monitor sensors concurrently, perform hot-word detection, and respond to user inputs without delays or interruptions. This architecture design makes the system reliable, efficient, and easily scalable for future upgrades and modifications.

AWS Services

The proposed system adopts an innovative solution to enhance the Bahrain museum visitor experience by developing a tour voice-activated assistant and hologram displays integrated with Amazon Web Services (AWS). These services are as follows:

AWS Lex - AWS Lex was utilized to facilitate communication between the user and the chatbot. Session attributes were utilized to manage the context of the conversation and ensure a seamless exchange. The SOX utility was also employed to capture and process audio input from the user, which is then passed to AWS Lex for natural language understanding and response generation. This integration of technologies allows for a smooth and intuitive user experience.

Simple Storage Solution bucket (S3) - The artifacts displayed through the hologram system are stored as images and video files in a private Amazon S3 bucket (Amazon S3, 2023). To guarantee secure access the bucket can only be accessed by authorized museum users with valid credentials. No visitor data is stored alongside the artifacts. User interactions such as voice input are processed in-memory using AWS Lex without retention of private information. The S3 architecture provides reliable storage and convenient organization and retrieval of the high volume of digital artifacts. By keeping artifact storage separate from ephemeral visitor interactions, user privacy is maintained while leveraging the durability and scalability benefits of S3 for robust museum content management. The proposed system implements a high-security, privacy-focused architecture for artifact storage and interaction handling.

AWS Lambda - A Lambda function is a serverless computing service offered by AWS. It is a code execution service that allows developers to run code without managing servers. Events trigger Lambda functions and can perform various tasks, such as responding to user requests, managing databases, and processing images. Lambda functions are cost-effective, scalable, and reliable, making them an ideal choice for various tasks. The proposed solution architecture used the Lambda functions Router Lambda, Write Record, Leaderboard, Image Handler, Update events, Update intent, create intent, and Send Frequency. According to the system architecture diagram in Figure 2, the API Gateway allows a client to easily modify the behaviour of the proposed system by updating intents. The update intent function is a Lambda function triggered by the API Gateway, which takes in a request with a JSON body containing the ID that is obtained from the Amazon Timestream database of the intent to be updated. The Image Handler lambda function manipulates images and prepares them for display as holograms (AWS Lambda, 2023).

API Gateway - The system utilizes API Gateway to trigger AWS Lambda functions that handle various chatbot functions. The API Gateway exposes endpoints that can be called to update, create, and fulfill intents in the chatbot. The update intent endpoint triggers a Lambda function that allows updating the name, sample utterances, and fulfillment for an existing intent. The create intent endpoint triggers a function to create a new intent in Amazon Lex and store details in DynamoDB. The fulfill intent endpoint triggers an Intent Handler lambda function responsible for retrieving answers from DynamoDB and returning an appropriate response. The API Gateway also triggers a Write Records lambda function to store user interaction data in the Timestream database. Using the API Gateway to expose endpoints and trigger lambda functions allows for an event-driven, serverless architecture.

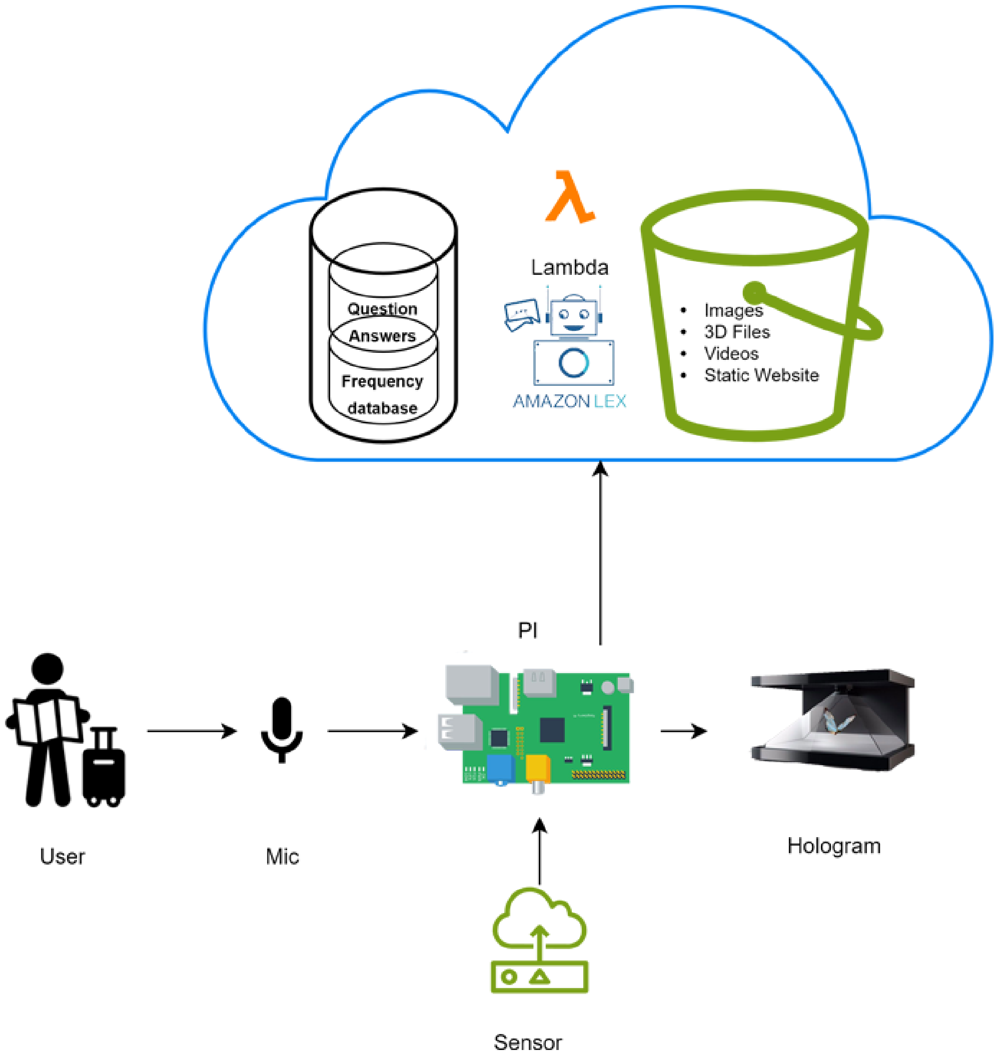
The proposed system design for the Museum of Bahrain solution leveraged an Agile development methodology, emphasizing flexibility, collaboration, and iterative development (Rasnacis & Berzisa, 2017). A microservice architecture was employed, facilitating easy adaptation of the system to evolving business needs over time. Each microservice serves a distinct purpose and interacts with other services through lightweight APIs. This approach enables greater flexibility, agility, and scalability because each microservice can be updated or replaced independently without impacting the rest of the system. The system architecture was designed based on the AWS Well-Architected (2022) to understand the internal functioning of the proposed system. The conceptual framework architecture provides a representation of the proposed system. User stories, which outline end-user needs and goals, drove the solution design (Bik et al., 2017). The role of software engineering in developing the proposed system was to leverage agile methodologies and microservice architecture to build a reliable, efficient, and readily scalable system that can accommodate future upgrades and modifications (Datta & Mirza, 2020). The proposed solution is built upon Amazon Web Services (AWS) serverless services, with automatic scaling capabilities. Specifically, the architecture leverages AWS Lambda functions, Amazon DynamoDB databases, and other fully managed AWS offerings. By using these auto-scaling services as the foundation, additional infrastructure provisioning and capacity planning are handled automatically by AWS. This scalable serverless architecture simplifies system administration and allows the solution to handle fluctuations in usage. For the museum of Bahrain, the proposed system designs an AWS well-architected framework, scalable, and flexible system that can adapt to evolving business needs over time. Using an Agile development methodology and a microservice architecture, along with AWS serverless services, enables the system to be reliable, efficient, and readily scalable. Such an approach allows easy modification and upgrading of the system, ensuring that it can meet the needs of the Museum both now and in the future.

IMPLEMENTATION AND RESULTS

Figure 3 examines the proposed system response that utilizes an ESP32 microcontroller to detect motion in a specific location. Ultrasonic sensors are used for motion detection to greet users and to show them how the system works using 3-D hologram interface.

In Figure 3, the AWS Lex service returns a response to a user's question using the holographic display. The response shows the requested artifact, a bag of coins, presented in 3-D through the hologram. The high level of accuracy in the 3-D rendering is made possible by 3DF Zephyr software, which captures and processes images of the artifact to create a detailed 3D model (Hilal et al., 2022). The process involves capturing a video of the artifact in 1080PPI resolution, which is then scaled down to 720 PPI to fit seamlessly into the holographic display without compromising quality. By leveraging the capabilities of 3DF Zephyr software, the proposed system offers a high level of visual detail and accuracy, enhancing the overall user experience. The proposed displays artifacts

Figure 3. Proposed system response



more realistically using holographic technology; it also features a chatbot component that allows users to ask general and specific questions about the museum and its exhibits. The proposed system utilizes Natural Language Processing (NLP) to comprehend semantically user queries /requests and provide accurate and relevant responses. This enables a smooth interaction experience from the user's perspective when using the holographic interface. For example, when a visitor inquires about the museum's operating hours, the system initiates a multi-faceted response process through its 3-D holographic interface. Initially, the 3-D hologram system displays a visual cue, signaling its recognition and processing of the query. Upon locating the necessary information, the system audibly articulates the operating hours, providing a clear and concise spoken response through the holographic display. This sequence of visually acknowledging the query, processing it efficiently, and culminating in spoken feedback allows the system to engage with the users through Friendly and Expressive Interfaces. Using this interface form increases the user's interactivity with desirable aspects of user experience goals and improves system usability. According to Rogers et al. (2015), a human-computer system's user experience (UX) is defined as the quality of a user's experience when interacting with the system. This includes the user's physical, cognitive, and emotional experience (Rhiu et al., 2020; Rogers et al., 2002).

As depicted in the conceptual framework of the proposed system architecture diagram in Figure 2, each component is independent and communicates with the others mainly through APIs. This solution architecture design allows the system to continue functioning normally even if one component fails or is removed, making maintenance and upgrades easier. This modular design is crucial to the overall reliability and robustness of the system, making it easy to troubleshoot and modify as required. In addition, using Docker containers offers further flexibility and scalability (Brady et al., 2020). It enables components to be replaced or modified without affecting the entire system. Even if you want to change the computing power of the system, you can do it easily by changing the Raspberry Pi to a more powerful computer (Wang et al., 2019). The proposed system uses the Amazon Timestream database to store time-series interaction data, as shown in Figure 4. For each interaction, the database captures the intent triggered, the source website/platform, the question wording, and the answer provided.

By analyzing this time-series data, the system identifies trends to optimize performance. For example, the system can track the intent types frequency, source platforms, and changes in interaction patterns. This analysis provides insights into improving the system's knowledge and interactions. Amazon Timestream is ideal for this time-series data. It is optimized for storing and analyzing time-series data like the interaction logs. The analysis can identify areas for improvement to best serve people's needs. The proposed solution of Museum-Guide development system uses Amazon Timestream to log detailed interaction data over time. Analyzing trends in this data helps optimize the system. Amazon Timestream captures each interaction's intent, source, question, and answer. This time-series dataset enables analyzing intent frequency, source platforms, interaction changes, and improvement opportunities. By tracking patterns over time, the analysis identifies ways to enhance the knowledge and interactions to best meet visitor's needs.

The new name, sample utterances, and fulfillment for the intent which is shown in Figure 5. It also updates the answer for the intent in the DynamoDB table, which triggers the AWS lex service to rebuild the bot using the update bot method. This flexible design allows easy editing of the system questions and responses, making it easy to adapt to changing user needs. Its primary responsibility is to create a new intent in the Amazon Lex service and add an entry for that intent to a DynamoDB

Figure 4. Web page consuming the API to determine the most frequent questions

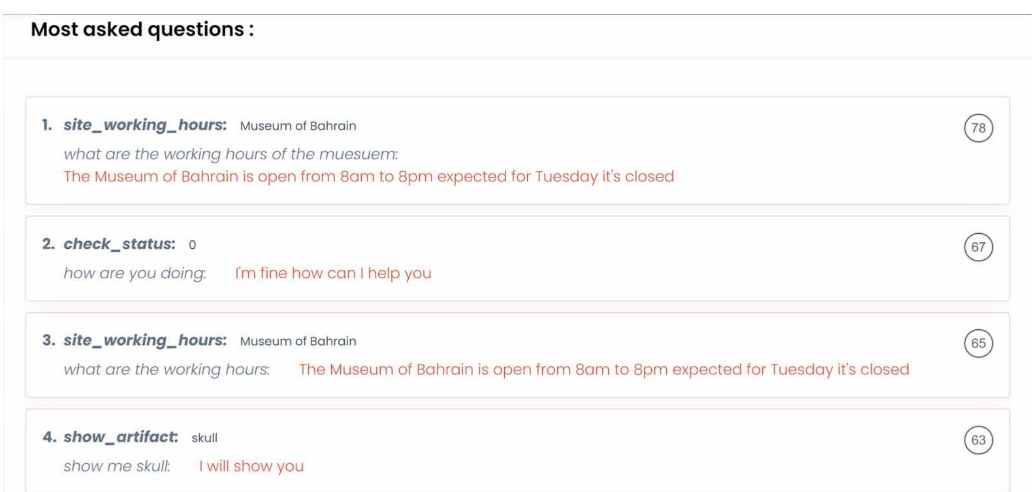


table. To implement this stage, the function first receives a request with a JSON body from the client, which contains the intent name, sample utterances, and fulfillment text shown in Figure 5. It then uses the Amazon Lex client to create the new intent. Then, the AWS lex service will rebuild the bot using the update bot method.

There are various ways to consume an API. While using a webpage is one option, it is not the only one available (Huang et al., 2018). In fact, many other ways to access an API can offer different benefits. For example, a mobile application can provide a more user-friendly API access interface. This is because the interface can be designed specifically for mobile devices, making it more intuitive and easier to use (Ghanem & Alkhal, 2018). The developers may use a command-line interface (CLI) to access an API. Next, the function adds an entry for the new intent to a table, including the intent name and the provided fulfillment text, using the DynamoDB client. Finally, the function updates the environment variables of a Lambda function to include the new intent name and maps it to a specified function. This enables the Lambda function to handle incoming requests for the new intent and respond appropriately to the user.

Figure 6 shows the sequence diagram of executing museum visitor scenarios by the proposed system. When museum visitors approached the interactive response system to inquire, “Can you tell me more about the pottery exhibit?” the system initiated a sophisticated question-answering protocol utilizing cloud computing services for natural language processing, serverless computing, and NoSQL database functionality. Specifically, the AWS Lex platform analyzed the linguistic content and intent of the inquiry via pre-trained machine learning models. The visitor’s question was routed to a serverless AWS Lambda function designed to handle exhibit-related information requests by interfacing with the museum’s DynamoDB knowledge base, which returned the relevant exhibit details to the function. To deliver an engaging visitor experience, the Lambda function transmitted the answer to a Raspberry Pi microcomputer, which projected a holographic display of the retrieved information. Finally, to provide museum staff visibility into visitor interests, a separate Lambda function recorded analytics derived from the natural language question into designated DynamoDB tables, enabling data-driven improvements to future exhibitions. This automated sequence demonstrated seamless integration of cloud services for natural language processing, serverless functionality, NoSQL data storage, microcomputing, and holographic projection to provide an informative and interactive museum experience.

The proposed museum-guide system aims to enhance the existing infrastructures and databases through flexible and API-based architecture. It leverages the museum’s rich data

Figure 5. Web page consuming the API edit/add the question

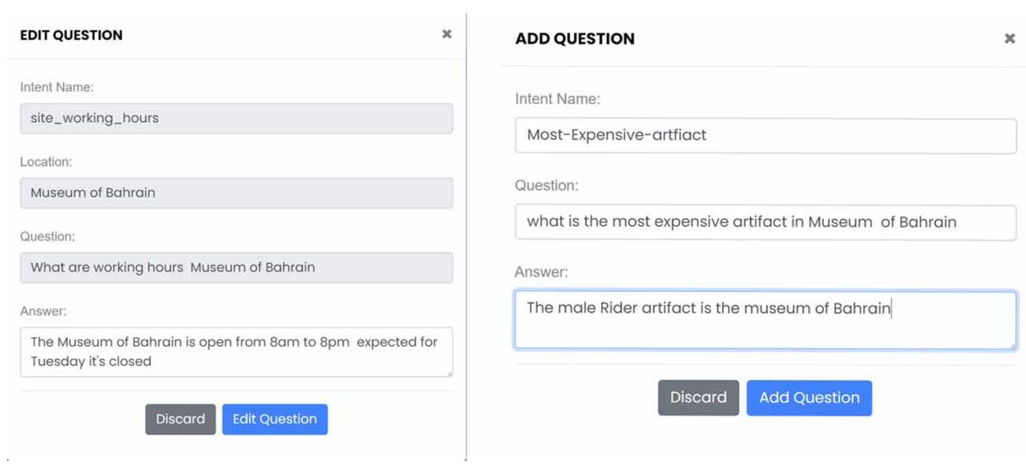
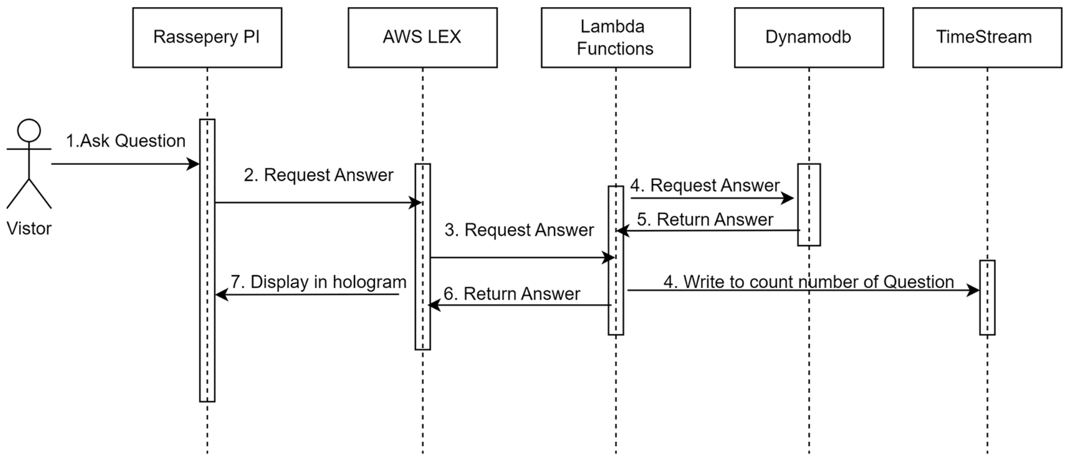


Figure 6. Sequence diagram of the "providing information of pottery exhibit" scenario



by directly accessing content management systems and databases via APIs. The system uses a lightweight integration approach with modular components and open APIs to pull and visualize data through interactive displays. This approach enables bidirectional data flow, capturing user analytics and interactions for feedback into museum databases. The focus is on value-add through supplementation rather than replacing current infrastructure completed during the data-gathering phase.

System Performance Analysis

Figure 7 illustrates the text latency performance evaluated based on Amazon CloudWatch (AWS CloudWatch, 2023). By enabling DynamoDB Accelerator (DAX), a fully managed in-memory cache for DynamoDB shown in Figure 7, the read latency can be reduced significantly. Additionally, provisioning Lambda functions asynchronously using event triggers can further decrease latency. When an event triggers a Lambda function, if the function is already provisioned, AWS Lambda can reuse the existing instance, avoiding the latency of initializing a new instance. By caching data in DAX and reusing Lambda instances, the text latency is minimized, resulting in a fast and responsive conversational experience using Amazon Lex, as shown in Figure 8.

Figure 9 shows that provisioned concurrency is critical for optimizing serverless applications' performance, cost, and user experience. Keeping a pool of Lambda functions initialized and ready to handle requests instantly can eliminate the latency and unpredictability of cold starts. This results in consistent low latency invocation performance, improved efficiency through reusing objects across requests, cost savings from not paying for initialization time, and a smooth experience for end users. Furthermore, implementing provisioned concurrency has proven instrumental in reducing specific requirements tied to two key metrics: the latency between audio and video and the video streaming quality. The optimization achieved through provisioned concurrency has resulted in a remarkable decrease in data transfer requirements, specifically lowering the bandwidth consumption from 150 Mbps to 10 Mbps. Additionally, a strategic change in the Region of Amazon S3 storage to the Bahrain region has played a pivotal role in achieving these improvements.

In summary, provisioned concurrency not only addresses the intrinsic challenges of serverless architecture but also brings tangible benefits such as reduced lag, improved video quality, and significant savings in data transfer costs, thereby contributing to an enhanced multimedia streaming experience. The program executes an infinite loop within the main function, performing several key operations during each iteration. These include triggering wake words or sensors (O(1)), initializing

Figure 7. Text request latency

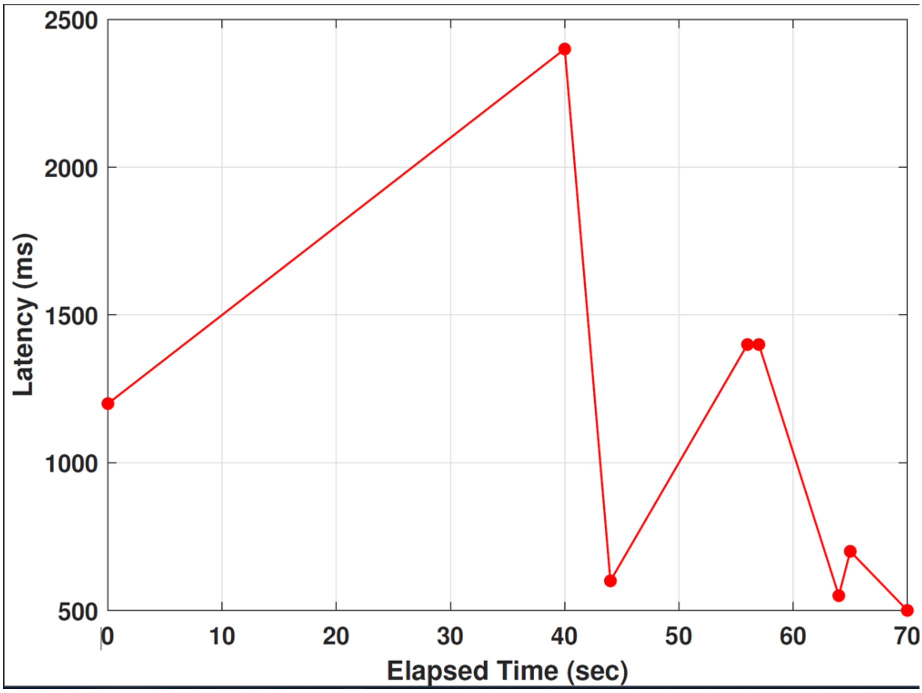
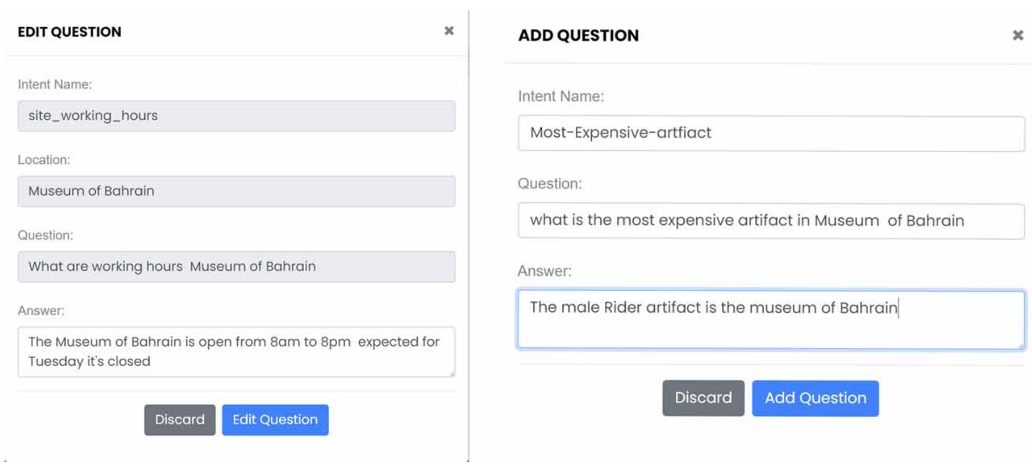


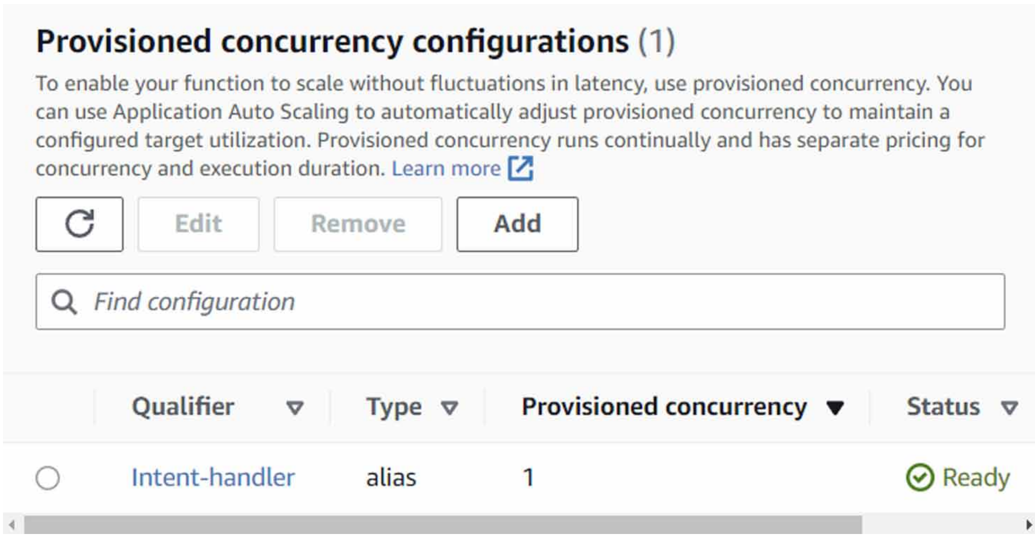
Figure 8. DAX configuration



Lex sessions (O(1)), recording variable-length audio (O(n)), invoking Lex APIs (O(1)), and playing assets (O(1)).

The dominating factor in each loop is the audio recording, which scales linearly with the length of audio in samples (n). Thus, each iteration of the main loop has a complexity of O(n). As this loop continues indefinitely, the algorithm has an unbounded runtime formally described as O(∞). In practice, factors such as audio duration and total execution time impact the scalability. However, with an infinite loop present, the program cannot reach a steady state, and the runtime grows perpetually.

Figure 9. Provisioned concurrency configuration



In summary, while individual iterations have linear complexity based on input length, the decision to continuously loop introduces an infinite computational profile. Mitigating this infinite growth would require modifying the program structure to avoid or exit the unconstrained repetition.

The proposed system represents a cost-effective solution for enhancing the museum experience by employing commercial hardware and cloud-computing services. This cost-effective solution not only aligns with budgetary constraints but also demonstrates efficiency in resource utilization, making it a viable choice for museums seeking to enhance their exhibits in a financially prudent manner. While offering innovative integration of technologies, the proposed solution has certain limitations. The unprecedented integration of diverse features posed engineering challenges requiring significant reimagining of functionality. Limited initial access to holographic equipment slowed progress, resulting in a simplified proof-of-concept. Leveraging the cutting-edge yet largely undocumented Amazon Lex v2 entailed difficulties, including a lack of Arabic support. Performance constraints intrinsic to Raspberry Pi hardware necessitated time-consuming optimization mitigation. More significantly, with AWS services hosted externally, latency emerges as a barrier to seamless interactivity. The vision of rich multi-modal interplay between visitor and system remains partially constrained by the technical realities of cloud dependencies and client-side limitations. Progressing beyond basic question-and-response towards deeper engagement would further tax current infrastructure. While promising, the proposed solution warrants expanded investment and maturation before ultimately delivering on ambitious promises of intuitive human-computer interaction. Ongoing enhancement of speech functionality, localization, hardware integration, and mitigating latency is needed to transform the prototype concept into a market-ready interactive exhibit.

CONCLUSION AND FUTURE WORK

This research has been conducted to design and implement the museum-guide system with an innovative cloud computing solution to enhance the museum visitor experience. It adapts a voice-activated assistant and integrates 3-D hologram displays into Amazon Web Services. The development of the system is based on the AWS Well-Architected Framework to provide high scalability and availability in line with other pillars of the cloud computing framework, such as security, performance efficiency, and cost optimization. The use of APIs for updating and editing the proposed museum-guide system allows for future expandability, making adding new features and capabilities to the AR system easier. In addition, the proposed museum-guide system developed based on cloud-computing power, driven by optimized code and efficient algorithms, is more efficient. In other words, the system's software makes it more efficient and responsive by providing a smooth and seamless user experience.

Compared with the existing museum guide - systems, the capabilities of the proposed museum guide system reveal substantial benefits from the impact of cloud computing to enable software engineering development and deployment capabilities in creating and testing the proposed system without investing in expensive infrastructure. Software developers can access various tools and services, such as development environments, testing platforms, and deployment tools. It provides enhanced security and improved data security for software development. Its impact is reflected in promoting collaboration, scalability, and efficiency and harnessing the power of the cloud, leveraging its potential to build innovative, robust, and scalable for the proposed museum system.

Furthermore, the proposed museum-guide system creates an immersive and engaging user experience using 3-D hologram technology. By incorporating more software engineering principles, such as responsive design, accessibility, and security, the proposed system enhances the user's experience for museum visitors. Also, the proposed system benefits from incorporating user feedback to continuously improve its functionality and features.

However, the system's functionality can be improved through user experience and enhancing language capabilities to include additional languages such as Arabic. Alternatively, provide sign language interpretation through video or animations to support hearing-impaired users. Expanding its knowledge-base and incorporating user feedback, the system can continue to evolve and improve to meet the needs of museum visitors and enhance their understanding and overall experience. Similarly, incorporating enhanced interactive AR museum system features by incorporating gamification elements, such as quizzes, challenges, or scavenger hunts, into the AR experience will make it more interactive and entertaining for visitors. This can increase engagement and encourage visitors to explore more of the museum. To this end, the proposed innovative system has the potential to transform the way visitors explore and interact with sites.

Despite the challenges faced during its development, the system offers improved performance, ease of use, and a more immersive user experience using hologram technology. We suggest improving the content creation of the AR museum system by investing in creating high-quality 3-D models, animations, and interactive elements that enrich the user experience. Collaborations with artists, designers, and developers can ensure engaging and visually appealing content is created. Incorporating software principles such as responsive design, accessibility, and security can further enhance the user experience and ensure the system's success in the market. In addition, the system's efficiency and responsiveness ensure a smooth and seamless user experience.

For future works, this research can be extended to examine the impact of user culture in designing the User Interface (UI) of the proposed system to study the user's behavior to improve the quality of the user experience; this could involve surveys or interviews with museum visitors who interact with the voice-activated assistant and holographic displays. This research can be extended by implementing personalization features, such as recommending related exhibits or providing customized content based on user preferences or past interactions. It creates a more tailored experience for each visitor and enhances their satisfaction.

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