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DEVELOPMENT AND RESEARCH OF A SERVICE FOR DELIVERING PERSONALIZED CONTENT TO VISITORS OF OPEN-AIR MUSEUMS

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The dissertation contains 239 pages. The scientific content is presented in an introduction, 4 chapters and 4 annexes and includes 70 figures and 10 tables. 158 literature sources are cited. The numbering of formulae, tables and figures in the Abstract corresponds to that in the thesis.

The development and research of the dissertation was carried out at the Department of Computer Systems and Technologies, Faculty of Electrical and Electronic Engineering, Technical University - Gabrovo.

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The reviews and opinions of the members of the scientific jury and the abstract are published on the university website: www.tugab.bg.

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CONTENTS

Abbreviations used

Abbreviation	Abbreviation means
AI	Artificial Intelligence
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
AR	Augmented Reality
BLE	Bluetooth Low Energy
FCM	Firebase Cloud Messaging
Geohash	Geohash Encoding
GeoJSON	Geographic JavaScript Object Notation
GPS	Global Positioning System
HTTPS	Hypertext Transfer Protocol Secure
iOS	iPhone Operating System
IoT	Internet of Things
ML	Machine Learning
NFC	Near Field Communication
OAuth	Open Authorization
OS	Operating System
RSSI	Received Signal Strength Indicator
UI	User Interface
UUID	Universally Unique Identifier
VR	Virtual Reality

GENERAL CHARACTERISTICS OF THESIS

Introduction and Relevance

Digitalization is profoundly changing social life, affecting cultural institutions, including museums. In the context of increasing expectations to adapt to individual visitor preferences, contemporary museums are moving beyond their traditional role as custodians of cultural heritage. Today they are becoming dynamic spaces for education, entertainment and social communication. The opportunities provided by new technologies such as artificial intelligence (AI), machine learning (ML) and the Internet of Things (IoT) open prospects for museums to offer personalized content and enrich audience interaction.

Personalization is key to achieving museums' strategic goals. By analyzing visitor interests and behaviors, personalized itineraries are created that increase satisfaction and provide valuable feedback for effective resource management.

The main challenge is combining tradition with modern requirements for digitization. Open-air museums provide a unique opportunity to integrate technological solutions due to their specific organization and interaction with visitors.

This dissertation focuses on the development and implementation of a personalized content delivery service for outdoor museum visitors. The research includes the creation of microservice-based architecture, algorithms for audience segmentation, and applications for tracking and adapting content according to individual preferences.

The importance of this topic is driven by the growing need for museums to be competitive in the age of digitalization. Successful implementation of personalized approaches can not only increase attendance and audience engagement but also establish museums as modern cultural and educational centers.

Aim and objectives of the dissertation

The aim of this dissertation is to design, develop and experiment with a system for delivering personalized content to visitors in outdoor museums using advanced positioning and identification technologies.

To achieve the goal, the following tasks are defined and solved:

1. To analyze current technologies and methods for delivering personalized content in a museum environment.
2. To develop the service design for personalized content delivery with distributed architecture based on microservices.
3. To develop a generalized algorithm for personalized content delivery service.

4. To propose a user segmentation methodology for better personalization of the delivered content.
5. To develop a prototype and minimum viable product of a mobile application, part of the service offered.
6. To design and test microservice for delivering personalized content to museum visitors using an interface to a Generative Artificial Intelligence (GPT API).
7. To design and implement a multimedia content delivery service using BLE beacons.
8. To develop a content delivering module using NFC technology for specific museum exhibits.
9. Experimentally validate the proposed service.

Materials and methods

The research is based on an integrated approach that combines quantitative and qualitative data collection and analysis methods. The main materials and methods used in this dissertation are structured as follows:

1. Study of scientific literature

An analysis of scholarly literature related to smart museums, personalization technologies, and innovative approaches to cultural content management was conducted. For this purpose, international databases such as Scopus, Web of Science and Google Scholar were used. To realize this analysis, 140 publications directly related to the delivery of personalized content to museum visitors were extracted from available databases of scientific publications. Additionally, 18 publications not directly related to the delivery of personalized content were analyzed. Appendix 1 of this dissertation presents a statistical analysis of publications that are directly related to the delivery of personalized content in museums according to the PRISMA methodology.

2. Developing an architecture for the service

The personalized content delivery service is based on microservices, which allows scalability and flexibility of the system. Key components include:

- Business Logic: To manage the data and interaction between components.
- Mobile app.
- Visitor tracking infrastructure: BLE beacons, NFC tags and geofencing.

3. Audience segmentation methodology

The following approaches have been used for visitor segmentation:

- Demographic analysis: gender, age, nationality and preferences.
- Behavioral analysis: data on time spent in front of different exhibits and routes chosen.
- Contextual analysis: Real-time location recorded by BLE beacons and GPS.

4. Tracking and adaptation technologies

The following technologies are integrated to track visitor movement:

- BLE beacons: For localization in indoor and outdoor spaces with high accuracy.
- NFC tags: For interacting with exhibits and providing contextual information.
- Geofencing: For defining virtual zones around large exhibits and adapting content to the visitor's location.

5. Content personalization algorithms

A content personalization algorithm has been developed based on:

- Visitor segmentation: combining explicit and implicit profiling of museum visitors.
- Generative Artificial Intelligence: Generating visitor-specific responses tailored to the segments to which each visitor belongs.

6. Data analysis

Quantitative methods were used to process and analyze the collected data, including:

- Statistical analysis: To identify patterns.
- Visualization: Presentation of results through graphs and tables.

7. Testing and validation of the service

- A methodology has been proposed and implemented to test the service in a local environment under Windows 11 OS. The test infrastructure includes: a container for each microservice; a RabbitMQ message broker deployed in a cloud infrastructure; MongoDB database instances for each microservice; external Google Firebase and OneSignal services to deliver push notifications.
- Service validation is implemented in a local environment. The following functional tests are implemented: 1) Visitor registration; Detection of geofence proximity when updating the visitor position; Accurate segmentation based on the visitor position and its profile; Generation of push notifications; Delivery of relevant content according to the user segment; Correct processing of events when approaching an exhibit; 2) Performance tests; 3) Service reliability tests.

The applied methods provide a comprehensive approach to investigate the effectiveness of the proposed service and its potential for application in outdoor museums.

Scientific novelty

This dissertation presents an innovative service for delivering personalized content to outdoor museum visitors based on advanced technologies and distributed architecture through microservices. The scientific novelty of the research lies in the following:

1. **Development of distributed architecture**

   A novel architecture is proposed that integrates microservices, geolocation technologies (GPS, BLE beacons, NFC) and artificial intelligence (programmatic access to ChatGPT). This architecture allows flexible and efficient management of personalized content, considering the specificities of outdoor museums.

2. **Hybrid approach to visitor profiling**

   A hybrid profiling method that combines explicit (surveys, OAuth registration) and implicit (visitor behavior analysis) techniques is proposed. This approach allows a more accurate determination of visitors' interests and preferences, which improves the quality of the content provided.

3. **Integration of artificial intelligence**

   The use of ChatGPT allows the dynamic generation of real-time, text-based personalized content adapted to each visitor's profile. This improves interactivity and engagement by providing the opportunity for additional queries and information enrichment.

4. **Optimizing energy efficiency**

   The visitor tracking algorithm uses accelerometer data to activate GPS and BLE sensors, significantly reducing mobile device power consumption and extending battery life.

5. **Personalized recommendations**

   The system offers dynamically generated recommendations for exhibits based on current position, direction of travel, and historical visitor behavior data.

Applicability

The developed service for delivering personalized content in outdoor museums has wide applicability in the cultural and educational sectors. It can be deployed in different types of museums, including outdoor ethnographic museums, archaeological parks, historical sites, eco museums and other institutions that offer outdoor exhibitions.

Advantages for museums:

- Increase engagement: personalized content and interactive features increase visitor interest and enhance their experience.
- Optimize management: the system provides valuable data on visitor behavior that can be used to improve exhibitions and marketing strategies.
- Reduce costs: The use of advanced technologies such as BLE beacons and NFC tags reduces the need for physical guides and printed materials.

Benefits for visitors:

- Personalized experience: each visitor receives information tailored to their interests and preferences.
- Flexibility.
- Accessibility.

Future application guidelines:

- Integration with other platforms: Ability to connect with social media and educational platforms for wider dissemination of cultural heritage.

The service represents an innovative approach to modernizing museums by combining technology with cultural heritage and has the potential to become standard for similar institutions worldwide.

Approval of the thesis

The dissertation was reported and discussed at an extended departmental council of the Department of "Computer Systems and Technologies" at the Technical University - Gabrovo. The main results of the dissertation work have been published and reported in the following international scientific conferences:

- International Scientific Conference International Conference on Automation, Quality and Testing, Robotics (AQTR), Romania (Cluj-Napoca), The papers are indexed in Scopus;
- International Scientific Conference Digital Presentation and Preservation of Cultural and Scientific Heritage (DiPP), Bulgaria (Burgas). Papers are indexed in Scopus and WoS. Since 2024 the conference has a Scopus SJR;
- International Scientific Conference International Conference Automatics and Informatics (ICAI), Bulgaria (Varna). Papers are indexed in Scopus.
- International Scientific Conference Unitech, Bulgaria (Gabrovo). Papers are not indexed in known scientific databases.

STRUCTURE AND SCOPE OF THE DISSERTATION

The dissertation is structured in four main chapters (194 pp.) and four appendices (45 pp.) that systematically present the theoretical, methodological and practical aspects of the research. A brief description of the content of each chapter follows:

Chapter 1: Review of available literature

Discusses the relevance of the topic, the significance of the research and the current technologies used in the context of 'smart museums'. Methods of personalized content delivery and specificities of outdoor museums are analyzed. The chapter concludes by stating the aim, objectives and structure of the thesis.

Chapter 2: Delivering personalized content through microservices-based architecture

A detailed analysis of software architectures suitable for service development is presented. The technology stack, personalization algorithms, mobile application and economic aspects of the implementation are investigated.

Chapter 3: Museum Visitor Segmentation

The focus is on audience classification methodologies for adaptive content delivery. Segmentation criteria, user profile analysis and practical guidelines for museums are discussed.

Chapter 4: Visitor tracking technologies for content delivery

Analyzes localization solutions (NFC, BLE, geofencing) and the integration of generative artificial intelligence to deliver personalized content to museum visitors.

Conclusion

The main contributions of the research are summarized and directions for future development are proposed.

Appendices

Contains supplementary material including statistical analysis of the available literature, surveys and practical visitor profiling tools, and a methodology for testing and validating the service.

Chapter 1. Review of available literature

This chapter offers an analysis of existing methods for providing personalized content to museum visitors in both indoor and outdoor spaces. It analyses different technologies and approaches that museum institutions use to create personalized experiences, including interactive applications, mobile platforms and augmented reality.

The main objective

The chapter aims to identify and analyze innovative technologies and approaches to personalization that can be applied to outdoor museums. Particular attention is paid to modern methods of audience segmentation and building user profiles.

Key questions

1. What are the current technologies for delivering personalized content?
2. What are the approaches to visitor profiling and segmentation in museum practice?
3. What is the role of interactive technologies such as AR, VR and IoT in creating personalized experiences?
4. What are the challenges and barriers to implementing personalized services in outdoor museums?

Theoretical framework

The theoretical framework is based on interdisciplinary approaches that include:

- Theories from museology related to the role of museums as educational and cultural institutions.
- Methods from information technology, including artificial intelligence and recommendation algorithms.

Methods of literature analysis

The literature analysis was conducted according to the PRISMA methodology, which structures the process of identifying, screening and classifying relevant sources. The scope of publications examined covered the period from 2015 to 2024, and 140 articles from reputable scientific databases were included.

Data sources and key terms

Strings are used to search the literature, emphasizing terms such as "outdoor museums" and "personalization." Most publications were retrieved from IEEE Xplore (15.7%), ResearchGate (11.4%), ACM Digital Library (11.4%), MDPI (7.9%), Springer (7.9%), Teylor & Fransis (7.9%), and other platforms (Appendix 1 of the dissertation, Fig. 1.2).

Classification by publication type

Reports and articles accounted for 85% of research, while book chapters and web publications had a smaller share (Appendix 1 of the thesis, Fig. 1.3).

Focus on outdoor(open-air) museums

Only 22 of the publications analyzed focus on outdoor museums, highlighting the research deficit in this area (Appendix 1 of the thesis, Fig. 1.4).

Classification by technology

IoT and AI were the leading technologies with 20 and 11 publications respectively, followed by mobile apps and AR, each with 6 publications (Appendix 1 of the thesis, Fig. 1.5).

Trends by year

There has been a steady increase in research, especially after 2019, peaking in 2024 with 15 publications. This reflects the increasing attention to digitization and personalization in the cultural sector (Appendix 1 of the thesis, Fig. 1.7).

Main results

The analysis of the available literature shows that:

1. Publications on the topic demonstrate a steady increasing trend over the years. This shows the importance of personalized approaches in museum practice and their recognition by the scientific community.
2. The distribution of publications by year confirms that research related to personalized content remains significant. The topic continues to be the subject of considerable scholarly interest.
3. There is a lack of publications addressing the specific needs of outdoor museums.
4. Publications address a wide range of aspects including mobile apps, interactive exhibits, tailored content and audience segmentation. This highlights the complex nature of personalization.
5. Personalized content has been identified as a key factor in increasing visitor engagement and satisfaction.

The analysis of publications confirms that personalized content in museums remains relevant and significant for contemporary cultural and scientific practice. This trend highlights the need to implement new technologies and strategies to meet individual visitor needs and preferences.

Relationship to the overall concept

Chapter 1 provides a contextual and methodological foundation for the subsequent research and development of a personalized content service in outdoor museums. It identifies the key challenges and opportunities that determine the successful implementation of innovation in the cultural sector.

Conclusions

Chapter 1 analyzed current technologies and methods for personalized content in museums, identifying the lack of research on outdoor museums. Using the PRISMA methodology, 140 publications were analyzed, showing a growing interest in digitization and personalization in the cultural sector, highlighting the role of AI, IoT and interactive technologies in enhancing the visitor experience.

Chapter 2. Delivering personalized content through microservices-based architecture

Chapter 2 of the thesis focuses on the design and development of architecture for delivering personalized content in smart museums.

Main objective

The objective of Chapter 2 is to develop a microservices-based system that integrates advanced technologies such as geofencing, distributed architecture, and content personalization. The system is designed to provide personalized content adapted to each visitor's location and profile.

Key issues

1. What are the main advantages and limitations of different architectural approaches - centralized, decentralized and distributed?
2. How can personalized content be provided in real-time through the integration of microservices and technologies such as geofencing?
3. What are the main challenges in using architectures for open museums?
4. How can modern tools and protocols improve system performance and adaptability?

Theoretical framework

The chapter builds on the theory of software architecture and considers different approaches to building systems. Technologies such as geofencing, asynchronous communications, and NoSQL databases are used to provide dynamic query processing and content personalization.

Main results

1. **Analysis of architectural approaches: a** comparative analysis of the advantages and disadvantages of centralized, decentralized and distributed architectures is conducted. Distributed architectures were found to be most suitable for smart museums with large numbers of visitors.

2. **Proposed architecture:** A microservices-based architecture is developed that uses Node.js to build modular components, MongoDB for geospatial data management, and AMQP for asynchronous communication.
3. **Integration of geofencing:** A geofencing mechanism was introduced to enable the delivery of content tailored to visitors' location.
4. **Dynamic content management:** the system uses profiling and segmentation to adapt content to each visitor's interests and behavior.

Relationship to the overall concept

Chapter 2 justifies the key role of distributed architecture and microservices for delivering personalized content in the context of cultural and museum institutions. The proposed architecture supports the main goal of the thesis, which is to develop effective technological solutions for personalization based on advanced technologies.

2.1 Architecture of the proposed service

Fig. 2.1 shows the architecture of the proposed service.

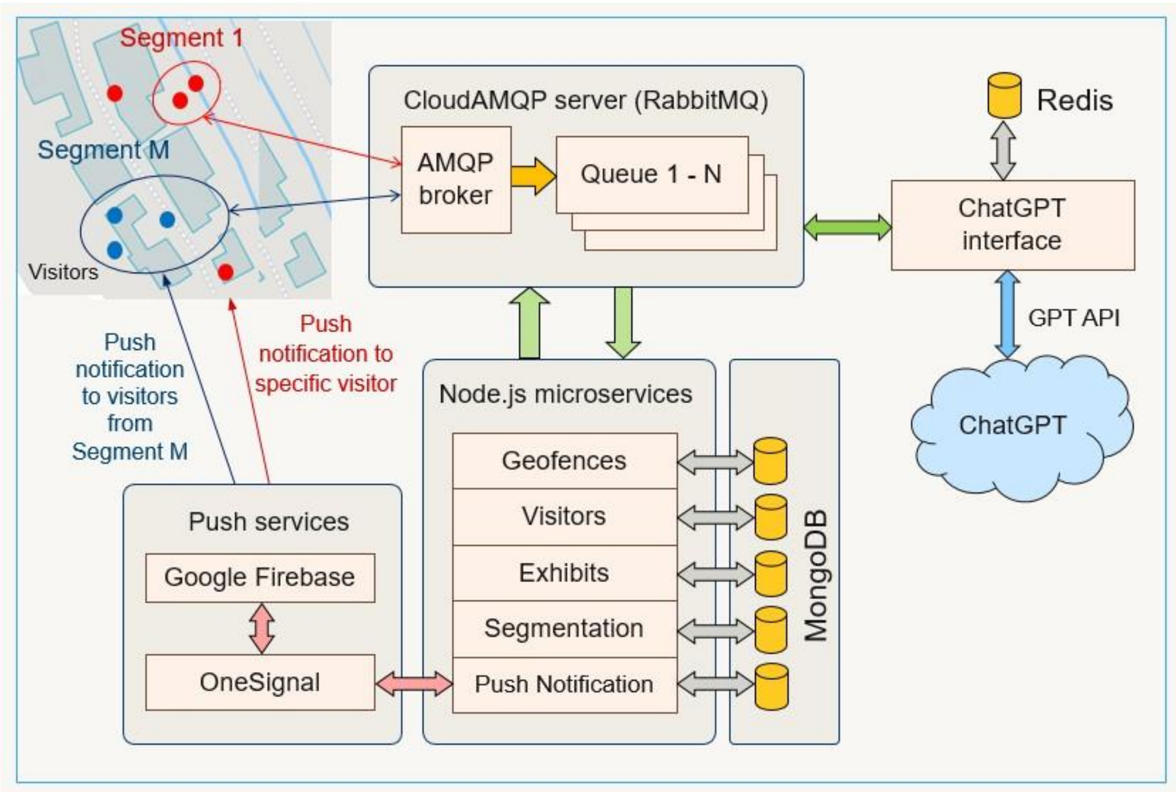

Fig. 2.1 Service architecture for the delivery of personalized content in outdoor museums

The proposed architecture for personalized content delivery is designed based on microservices, providing high flexibility, scalability and personalization.

2.1.1 Key features of architecture

1. **Microservices and their role:**

    - Geofences: manages geofences described in GeoJSON format to define virtual boundaries around exhibits. This service provides a quick determination if a visitor is in a specific zone.
    - Visitors: implements registration of system users by identifying them through a OneSignal or OAuth registration service.
    - Exhibits: manages exhibit information using a modification of the ObjectID (for physical artifacts) and Dublin Core (for digital resources) standards.
    - Segmentation: profiles visitors based on location or profile data, enabling the delivery of personalized content.
    - Push Notifications: Sends notifications to all visitors, specific segments, or specific users through integration with OneSignal and Google Firebase FCM services.
    - ChatGPT interface: implements an interface to the ChatGPT service via the GPT API. The goal is to allow museum visitors to send requests to this microservice to deliver personalized text descriptions for exhibits. The visitor's current profile is added to the visitor's question and thus personalized content is generated.

2. **Communication and synchronization:**

    - Advanced Message Queuing Protocol (AMQP) is used for asynchronous and reliable communication between microservices.
    - A message broker, RabbitMQ is used to provide the ability to manage multiple message queues and ensure their reliable delivery.

3. **Data Management:**

    - MongoDB is used as a NoSQL type database allowing storage of geospatial data, visitor profiles and exhibit information.

4. **Customization:**

    - Geofencing allows dynamic activation of content when a visitor logs in or out of a geofence.
    - Visitors are segmented based on location and profile, allowing information to be provided related to their interests.

5. **Push notifications:**

- The OneSignal service provides push notifications with content to which exhibit the visitor is.

6. **Mobile App:**

   - The hybrid Android and iOS app provides a platform to register, receive personalized notifications and access exhibit information. The app communicates with the service via a message broker and uses data from microservices to tailor content.

2.1.2 Advantages of the proposed architecture

- Geofencing: Enables location-based content.
- Scalability: Distributed structure allows new microservices to be added without interrupting the system.
- Reliability: AMQP and MongoDB provide resiliency and fast query processing.
- Personalization.

The architecture combines innovative technologies and robust communication protocols, making it suitable for museums with large numbers of visitors. It provides an interactive, personalized experience through a flexible and scalable structure that can adapt to different museum settings.

2.2 Service operation algorithm

The service logic for delivering personalized content to visitors of outdoor museums is implemented in the following sequence:

Phase 1: Initialization and registration

Step 1-2: Mobile app installation and OneSignal registration. The visitor scans a QR code or NFC tag at the museum entrance or from the website in order to install the app. Upon launch, automatic registration is performed in OneSignal for push notifications, receiving the player_id.

Step 3-4: OAuth registration. The system attempts to perform OAuth 2.0 registration via Facebook, Twitter, or LinkedIn to obtain visitor_id and demographics. If denied, the player_id is used as the primary visitor_id.

Step 5-7: Profiling and Registration The visitor data is recorded in the database. Initial segmentation is performed by analyzing pre-poll and OAuth data. Visitor profile is created or updated with demographics and preferences.

Phase 2: Localization and activation

Step 8-9: GPS activation and location verification. GPS tracking is activated (only when moving according to the accelerometer for energy efficiency). The system checks if the visitor is within the museum boundaries every 15 seconds until the presence is confirmed.

Step 10-11: Multisensory tracking. Upon entering the museum, NFC and BLE channels are activated. Combined tracking via GPS, BLE beacons, and NFC tags begins to pinpoint the visitor's position.

Phase 3: Interactive profiling

Step 12: Explicit Profiling. If there is no movement for more than 15 seconds, polling is triggered. The visitor can reject or partially answer the questions. The answers are used to update the visitor's profile.

Step 13: Implicit profiling. GPS positions, BLE approaches, and NFC scans are tracked in parallel. Visited exhibits, consistency, and time spent on each exhibit are analyzed.

Phase 4: Personalized content

Step 14: Smart Notifications. A push notification is sent when a geofence is entered around an exhibit. The system manages the frequency of notifications, reducing it when “notification fatigue” occurs.

Step 15: Dynamic Content When a request is made to receive information about an exhibit (“opening” a push notification), customized content is returned according to the user profile (text, photos, video, and audio). The visitor can rate the content (1-5 stars) and make additional requests via ChatGPT.

Phase 5: Closure

Step 16-17: Monitoring and Completion The system continuously checks the visitors’ presence in the museum. Upon exiting the museum boundaries, a thank you message is sent, and the session is ended. Upon remaining in the museum, the process returns to step 12.

2.3 Cost analysis

The cost of the service has been analyzed for the Ethnographic Open-Air Museum “Etar”. Two implementation approaches are considered:

1. **With Kio Cloud (a cloud service of Kontakt.io) -** provides high accuracy through machine learning and business analysis capabilities but is more expensive (165,700 BGN in total).
2. **Without Kio Cloud -** cheaper (~147,300 BGN), with local data processing in the mobile app, but lower accuracy and no business analytics.

Key components and costs:

- Hardware: from BGN 2,300 to BGN 20,300 depending on the architecture chosen.
- Cloud services: 10,000-10,400 BGN.
- Microservices (business logic): 65,000 BGN.
- Mobile application: 50,000 BGN.
- Other costs (integration, training and marketing): 20,000 lv.

2.4 Experiments

Tests have been performed in an on-premises environment without using Kio Cloud because of lower costs, greater flexibility and less integration complexity.

2.4.1 Architecture validation methodology

Within the research, a methodology was developed to validate the proposed microservices architecture for personalized content delivery in outdoor museums. The methodology includes functional, integration, and performance tests conducted locally deploying five main microservices: Geofences, Visitors, Exhibits, Segmentation, and Push Notifications, communicating via RabbitMQ message broker.

The test environment was designed for maximum reproducibility and implemented using Docker containers for each microservice, a RabbitMQ server in Google Cloud Platform, local MongoDB instances for each service, external OneSignal and Google Firebase services, and a query generation simulator.

2.4.2 Test environment configuration

System requirements and settings

The methodology is designed to run in a Windows 11 Pro/Enterprise environment with Hyper-V support, Docker Desktop with WSL2 (Windows Subsystem for Linux 2), and PowerShell 7.1+.

Architectural deployment of components

Microservices are deployed using Docker Compose configurations, with each service connected to the common museum-network. Data persistence is ensured through Docker volumes and the necessary port mappings for external access are configured. This approach provides an isolated and controllable test environment.

2.4.3 Test scenarios and procedures

Functional tests

Validation of the registration process: test procedures have been developed to validate visitor registration. The methodology includes verification of correct processing of registration requests.

Geospatial tracking: Test procedures were implemented to update the location of visitors, including processing GPS coordinates, determining active geofences using MongoDB operator $geoWithin, updating database positions, and location-based segmentation.

Content personalization: a methodology was developed to test combined location-based and profile-based segmentation by creating complex user profiles including demographics, preferences and visit history.

Integration tests

The methodology includes validation of communication flows between components: mobile application → RabbitMQ → microservices → database → external services. Different interaction scenarios are developed including registration, location update, proximity detection to exhibits and updating user profiles.

Performance tests

Geospatial operations: a methodology was developed to measure performance under high load with 1000 concurrent users, 50 updates per second over a period of 10 minutes. Different types of geospatial indexes (2dsphere, 2d) and geospatial queries were tested using$ near, $geoWithin and $ geoIntersects operators.

Reliability tests and chaos tests

Reliability tests are used to verify the stability of the system under normal and stress conditions. Chaos tests are used to simulate unexpected errors and crashes to verify how the system handles unpredictable situations.

Network resilience: procedures are developed to simulate network outages by disconnecting services from the network for specified periods. The mechanisms for automatic recovery and message handling after reconnection have been tested.

2.4.4 Evaluation criteria and expected results

Functional indicators

The methodology defines the following criteria: 100% success rate for visitor registration via OneSignal, correct geofence detection for location updates position and profile-based segmentation, successful generation of custom push notifications, and correct event handling when approaching exhibits.

Performance

The following benchmarks have been defined: location updates below 100ms, receive push notifications below 5 seconds, geospatial queries below 1ms, support for over 1000 concurrent visitors, and throughput over 1000 messages per second.

Reliability

The methodology provides validation of the resilience of the system to network failures, message recovery capabilities and the smooth degradation of external service failures.

2.4.5 Conclusions on the test methodology

The developed test methodology provides validation of the proposed architecture with microservices. It covers critical business processes and technical requirements, providing a solid basis for validating the scientific contributions in the field of personalized delivery of cultural content in outdoor museums.

Conclusions

Chapter 2 described the architecture of a microservices-based system. The system integrates geofencing, BLE, NFC, and an interface to ChatGPT to deliver personalized content to visitors of outdoor museums. Experiments demonstrate the effectiveness of the system in managing personalized content using asynchronous communication (AMQP) and optimized geospatial queries in MongoDB.

Chapter 3. Segmenting museum visitors

Chapter 3 of this dissertation focuses on the development of a methodology to segment museum visitors in order to build their individual profiles for personalized content delivery.

Main objective

This chapter aims to develop a methodology for segmenting museum visitors in order to deliver personalized content tailored to the individual interests, preferences and behaviors of different audiences.

Key issues

1. How can museum visitors be categorized according to different criteria (demographic, behavioral, technological, etc.)?
2. What segmentation approaches (explicit, implicit and hybrid) are applicable in a museum environment?
3. How to overcome the cold start problem in the absence of initial visitor information?
4. How is personalization implemented using a chatbot based on the GPT API?

A theoretical framework

The analysis shows that the most effective approach is hybrid segmentation, which combines:

1. Online pre-survey.

2. OAuth registration with data mining from social networks.
3. In-visit polling.
4. Behavioral data tracking within the museum using GPS/BLE technologies.

Based on statistical analysis of survey data from 551 respondents, a variety of visitor types are defined:

- demographic profiles (age, gender, geography);
- behavioral (dwell time, frequency of visits);
- visitor interests (type of museum preferred, type of content);
- technological orientation (traditionalists vs. digitally active).

Main results

Based on the study, an integrated multi-layer profiling methodology is proposed, which includes:

1. Automatic registration and data collection through a mobile application.
2. Adaptive content customization according to the segment you belong to.
3. Using ChatGPT to dynamically create relevant content.

Linking to the overall concept

This chapter is logically linked to the previous ones, building on the foundations of digitalization in the museum experience by introducing an innovative visitor segmentation technique for personalized visitor communication. It contributes substantially to the overall objectives of the thesis by providing a practically applicable model for increasing museum visitor satisfaction and engagement. The development of the argument in the chapter is sequential: from an analysis of the need for segmentation, to a description and implementation of specific techniques, to an evaluation of their impact and guidelines for data protection in line with the GDPR.

3.1 Segmenting museum visitors

A hybrid methodology for personalized content in a museum context based on a multi-layered user profile has been developed. The goal is an individualized information service tailored to the interests, behavior and context of each visit.

The visitor profile includes:

- Demographic characteristics (age, gender, geography).
- Behavioral indicators (frequency of visits, dwell time).
- Technological orientation (traditionalists, digitally active).

- Preferred content type (educational, entertainment, informational);
- Social context of visit (family, group, individual).

3.2 Visitor segmentation methodology

The segmentation of museum visitors in the proposed methodology is implemented in the following sequence:

1. Anonymous registration. After installation, the application automatically implements registration to receive push notifications, and the generated identifier player_id is used as a unique identifier for the visitor. This approach ensures that anonymity is preserved, and personal data cannot be directly linked to a specific visitor.

2. OAuth 2.0 integration. Using the OAuth 2.0 programming framework allows pseudo-explicit segmentation by indirectly accessing social media profile data, providing mainly demographic and geographic information.

3. Primary profiling. Initial visitor profiling based on registration data and pre-polling is implemented, which is preferred in the absence of initial visitor information.

4. Explicit online polling. Visitors receive short questions in the mobile app, which they answer voluntarily. Anyone can answer one or more questions or skip the survey. Segmentation is performed according to the following criteria:

- Demographic segments.
- Interests and preferences.
- Behavioral segments.
- Technology preferences.
- Willingness to interact.
- Content Type.
- Downtime.

5. Implicit profiling through geofencing. Automatically track visitor movement within the museum and accurately calculate dwell time to each exhibit. The technical implementation is done through BLE beacons and GPS positioning.

6. Deliver personalized content. A push notification informs the visitor when approaching an exhibit. Upon “opening” the notification, the service delivers personalized content tailored to the visitor's current profile. The visitor has the option to send a request to ChatGPT through which a personalized text response is formed. For this purpose, the visitor's profile is added to the request.

3.3 Experiments

In the context of a system for delivering personalized content to visitors in museums, segmentation represents a critical component. It aims to classify visitors based on behavioral data, location, and personal preferences to provide the most relevant experience.

Segmentation methodology

The segmentation process uses data obtained from the users' mobile app. The location information is transmitted to the server through a location.updates queue, while profile data and demographic characteristics, are sent through a segmentation.data queue. This data is processed by the Geofences and Segmentation microservices.

An important part of the process involves the geofences defined in the database, which allow the system to determine whether a visitor is in the museum or near a particular exhibit.

Conducting the experiments

The system was subjected to several test scenarios that validated its functionality and segmentation performance:

1. The first experiment focused on location-based segmentation. The mobile application simulated visitor movements in and out of defined geofences. The system identifies all boundary-crossing events and triggers appropriate actions.

2. In the second experiment, profile-based segmentation was tested. Visitor data, such as preferences and demographic characteristics, are updated through a survey. The system correctly updates the visitor's profile according to these changes.

3. The last, most complex test combines location-based and profile-based segmentation. Here, visitors received personalized notifications and recommendations that reflected both their current location and their personal preferences.

3.4 Conclusion

This chapter proposed a hybrid museum visitor segmentation methodology combining explicit, pseudo-explicit and implicit profiling. The analysis has shown that accurate and adaptive user profiles can be built by collecting data from surveys, social networks and behavioural analysis in museums.

Conclusions

A hybrid segmentation methodology combining explicit (surveys), pseudo-explicit (OAuth) and implicit (BLE/GPS) approaches is proposed. It enables dynamic visitor profiling by adapting content according to visitors' interests and behavior, which aims to increase visitor satisfaction and engagement.

Chapter 4. Visitor tracking technologies for content delivery

Chapter 4 of the thesis focuses on the technologies used to deliver personalized content to visitors of outdoor museums. The chapter also discusses all the services that have been developed using these technologies and their experimentation.

Main objective

The main objective of Chapter 4 is to investigate and propose technological solutions (GPS geofencing, BLE beacons and NFC tags) for the automated and adaptive delivery of information to visitors tailored to their interests, behavior and location.

Key issues

1. What technologies can be used to track visitors in real time?
2. What are the advantages and limitations of these technologies?
3. How can personalized content delivery be implemented according to the visitor's profile?
4. How do you build an effective content management and delivery system for multiple museums?

Theoretical framework

1. Geofencing.
2. Personalized content and user profiles.
3. Tangible user interfaces.
4. Generative Artificial Intelligence.

Main results

1. NFC tags, BLE beacons and geofencing are suitable for tracking museum visitors to deliver personalized content.
2. Push notifications are an effective channel for content delivery, including when the mobile app is inactive.
3. The implemented content tracking and delivery system works in real-time, with high reliability and scalability, proven through simulations and real tests.

Relationship to the overall concept

Chapter 4 logically builds on the previous ones by implementing a key functional module, the intelligent content delivery system. The argumentation in the thesis evolves from the presentation of concepts (in previous chapters), to concrete technological implementation and experimental validation, preparing the basis for the analysis of results and generalizations in the final part of the thesis.

4.1 Visitor tracking using NFC tags, BLE beacons and geofencing

NFC tags provide an inexpensive and easy way to deliver content via wireless data exchange over distances of 1-3cm. They require physical proximity, making them less effective in dynamic or outdoor museum environments.

BLE beacons are a more flexible solution - they emit signals that mobile devices pick up without the need for contact. This allows for passive content delivery and the creation of interactive experiences that are activated when exhibits are approached. BLE beacons also support the collection of behavioral data for better profiling and strategic planning.

When exhibits are large in size or located outdoors, geofencing, a technology used to create virtual zones based on GPS or BLE, is used. This allows accurate determination of when a visitor approaches, enters or leaves an area.

4.2 Service to deliver content to museum visitors through a tangible type of user interface

In the developed service, a tangible type of user interface is used to allow interactive and intuitive interaction of visitors with museum exhibits. This type of interface is suitable for cultural institutions as it reduces cognitive load and facilitates access to information through physical interactions.

4.2.1 Service architecture

The service architecture is shown on Fig. 4.1. It includes a hybrid mobile application, Node.js business logic, and a MongoDB database.

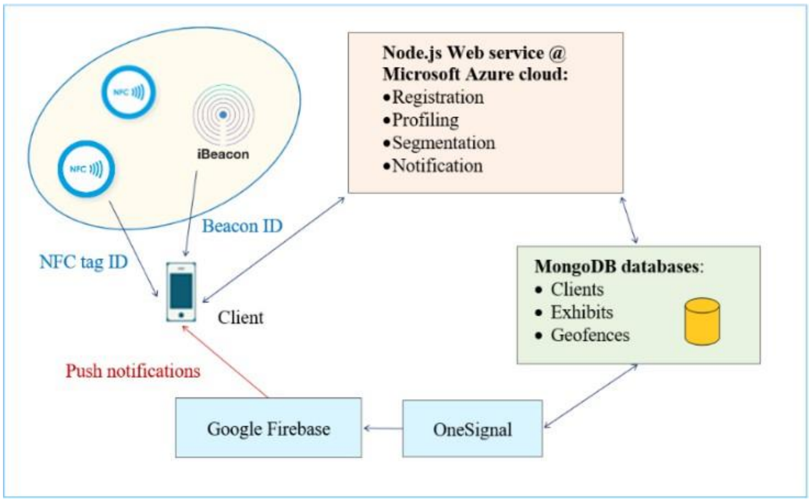

Fig. 4.1 The application architecture

The mobile application performs key functions such as scanning BLE beacons, reading NFC tags, and obtaining GPS coordinates. It uses the accelerometer to detect visitor activity (e.g. walking, immobility), which helps with dynamic profiling. The system delivers content via push notifications using the external OneSignal service.

The web service is responsible for processing the collected data and providing personalized content. It automatically profiles visitors based on time spent in front of exhibits and preferred media types. The service segments visitors based on their interests, which optimizes message delivery.

The database, implemented with MongoDB, stores information about customers, exhibits, and geofences. Each exhibit is described with identifiers, metadata and links to multimedia resources. The data is used to deliver personalized content and for strategic exhibit planning.

4.2.2 Experiments and Results

A prototype service architecture including a web application and a MongoDB database hosted in Microsoft Azure, as well as a hybrid Android mobile application, was developed and tested. The web application sends push notifications through Firebase Cloud Messaging (FCM) mediated by OneSignal, which facilitates sending to specific users.

NFC tags and BLE beacons from Kontakt.io were used for testing. The mobile app can scan BLE beacons and read the user's GPS position even when not active on the screen, and NFC tags are only read when the app is in focus. The app has been tested on Android versions 9, 11 and 12.

The database contains information about 20 real exhibits (NFC and BLE), 1000 virtual exhibits, 10 real and 1000 virtual clients, and 38 geofences from the Ether Museum. The response time for queries to the database is under 4 ms and the web service latency is under 500ms when using European servers. The multimedia resources are stored separately on a file server and only their URLs are stored in the database.

When scanning an NFC or approaching a BLE beacon, the app displays customized exhibit information according to the visitor's profile, which is unified regardless of sensor type. Similar information is displayed when entering a specific geofence.

We conclude that the architecture is validated in a simulated environment and provides real-time personalized content with efficient push notifications using cloud services and geospatial queries in MongoDB.

4.3 Multimedia content delivery service for multiple institutions using Bluetooth Low Energy technology

The developed service uses BLE beacons to deliver personalized multimedia content to museums and other cultural institutions. This service is designed to be scalable and applicable across different organizations, which differentiates it from existing solutions designed for individual institutions.

4.3.1 Service architecture

The system is built on an architecture (Fig. 4.7) including BLE beacons, a mobile application and a cloud database MongoDB Atlas.

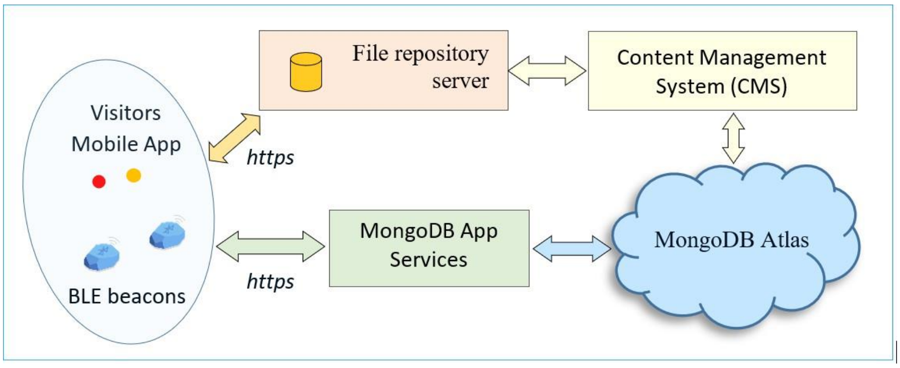

Fig. 4.7 System architecture for content delivery using Bluetooth Low Energy technology

The BLE beacons serve as the main mechanism for content localization and delivery by transmitting signals to the mobile application. The application uses these signals to identify the nearest exhibit and deliver relevant content to the user.

The cloud database stores information about organizations, exhibits, and geographic areas, providing centralized content management. Each exhibit is linked to a unique BLE beacon and described through text, images, video and audio resources. Data for these resources is synchronized with the mobile app via a secure HTTPS channel.

4.3.2 Methodology for estimating the value of the path attenuation exponent

For building a reliable BLE-based visitor localization system in cultural institutions, especially in open or mixed environments, a key element is to accurately determine the distance to beacons. For this purpose, the development uses the log-normal model, which gives the relationship between the signal strength of the beacons and the distance to them:

$$RSS_{k,d} = RSS_{k,d_0} - 10\gamma_k log_{10}\left(\frac{d}{d_0}\right) + N(x_0, x) \quad (1)$$

Where $RSS_{k,d}$ is the estimate of the signal strength from the k-th beacon measured at distance d; RSS_{k,d_0} is the estimate of the signal strength from the k-th beacon measured at reference distanced_0 (typically 1 m); γ_k is the path loss exponent for the k-th beacon, and $N(x_0, x)$ reflects random fluctuations in RSS due to various types of attenuation.

To locate the visitor, it is necessary to convert the RSS measurements to an approximate distance from the radio beacon:

$$d = 10^{\frac{RSS_{k,d_0} - RSS_{k,d} - N(x_0,x)}{10\gamma_k}}. \quad (2)$$

The analysis of (1) in the context of localization in outdoor museums shows that neglecting the random fluctuations $N(x_0, x)$ is justified due to the difficulty of accurately determining their standard deviation in complex environments. Such environments include variable factors such as visitors, temporary structures, atmospheric conditions, and vegetation, leading to systematic errors that outweigh the theoretical benefits of including $N(x_0, x)$ in the model. The simplified deterministic approach with $N(x_0, x)$=0 provides more robust and predictable results by allowing noise compensation through multiple measurements, adaptive calibration, and data filtering. This approach strikes a balance between theoretical accuracy and practical applicability, ensuring the stability and reliability of the localization system in real-world conditions.

Hence, an estimate of the value of the path attenuation exponent is needed to calculate the distance to the beacons γ_k. It can vary depending on the signal frequency and specific building conditions-from 1.5 for a Line of Sight (LOS) scenario to 3.5 for a Non-Line of Sight (NLOS) scenario.

In this dissertation, a methodology for calculating the attenuation exponent based on the log-normal radio signal propagation model is developed and experimentally validated. The methodology includes:

1. Conducting measurements in a controlled environment (indoor space with fixed dimensions and placement of BLE beacons), where received signal (RSSI) values are collected at various known distances from the source.
2. Aggregation of measured data into pairs (distance - RSSI).
3. Using non-linear regression via the curve_fit function (SciPy library, Python), which applies the Levenberg-Marquardt algorithm to estimate the attenuation exponent by minimizing the squared error between the measured and theoretical values.
4. Statistical estimation of the model by coefficient of determination (R^2), standard error, root mean square error (RMSE) and 95% confidence interval of the damping exponent.

The results of the applied methodology show a high degree of consistency with the theoretical model. Experiments in a real environment were conducted. The attenuation exponent has been estimated for 6 beacons. The coefficient of determination R^2 is 0.9526 and the root mean square error is 1.24 dBm. This demonstrates the robustness of the estimate and its potential for application in distance estimation in BLE-based navigation systems.

4.3.3 Methodology for calculating the fading exponent for different locations in an outdoor museum

Accurate localization in outdoor museum environments requires an adaptive model for estimating losses in the radio signal path, accounting for the influence of the environment on propagation. In this regard, this dissertation proposes a methodology for visitor localization using BLE beacons in the absence of sufficiently accurate GPS localization. The methodology assumes that the environment is not homogeneous - physical characteristics of areas (e.g. open areas, walkways, areas between exhibits, semi-open spaces, etc.) have a significant influence on the radio signal. Therefore, the value of the attenuation exponent cannot be treated as constant for the whole terrain but must be determined individually for each area.

The algorithm attempts to find the most accurate value of the attenuation exponent in the model for the propagation of radio signals in open spaces. It works iteratively, improving both the exponent estimate and the visitor position at each step.

The proposed methodology includes the following steps:

1. Initialization

The algorithm starts by deploying the N beacon within the museum. A visitor with a random position is created. An initial value of the attenuation exponent is set, and the end criteria of the algorithm is determined.

2. Simulation of signals

For each beacon, the received signal strength is simulated according to the mathematical model of radio signal propagation. White noise is added to this value to mimic real conditions.

3. Basic cycle

3.1 Selection of suitable beacons

From all available beacons, only those that meet certain quality criteria are selected. Beacons are first filtered according to distance and signal strength - beacons that are too close and those with too weak a signal are rejected. For the remaining beacons, a quality metric is calculated that combines the normalized signal strength and the inverse distance to the beacons:

$$w_i = \frac{1}{1+\left(\frac{d_i}{d_{th}}\right)^p}, \tag{10}$$

where w_i is the weight for a beacon with index i; d_i is the distance to the beacon i, d_{th} = 25m (threshold value for d) and p = 2 (stepped metric).

If $d_i \ll d_{th}$, then $w_i \approx 1$ - nearby beacons get a high weight. If $d_i = d_{th}$, then $w_i \approx 0.5$. If $d_i \gg d_{th}$, then $w_i \to 0$ - distant beacons get low weight but are not ignored. From all candidate beacons, M best beacons are selected for the current iteration.

3.2 Computing reliability weights

Each of the selected beacons is assigned a weight that indicates how reliable it is for the computation. Beacons at a smaller distance receive a larger weight because their measurements are more accurate. All weights are normalized so that their sum is unity.

3.3 Calculating a new value for the damping exponent

For each selected beacon, the attenuation exponent value is calculated using the measured signal strength and the distance to it. This local value indicates what the attenuation exponent value should be to match the observed signal strength. All local values are then combined by a weighted average, where the weights reflect the reliability of each beacon. This yields a new improved exponent estimate.

3.4 Position update

The position of the receiver (visitor) is computed using the trilateration method based on the analysis of the signals from the M beacon.

3.5 Edge check

The algorithm checks whether the changes in the attenuation exponent and the visitor position are small enough. If the termination conditions are met, the algorithm is considered convergent and terminates. If the changes are still large, the process repeats with the new values until convergence is achieved, or the maximum number of iterations is reached - transition to 3.

Testing the methodology

A simulation programming environment has been developed to test the proposed methodology. It is used to visualize the beacon position, the actual visitor position and the calculated visitor position as shown in Fig. 4.13.

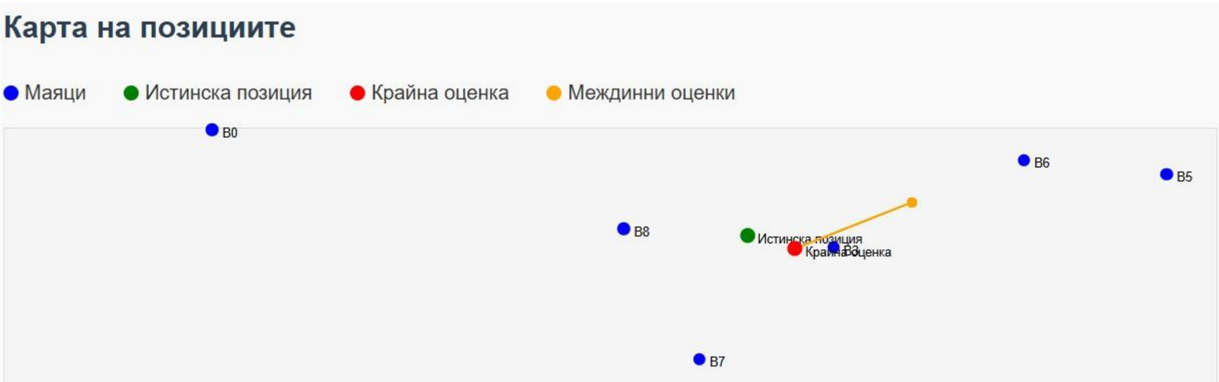

Fig. 4.13 *Results of the validation program of the methodology for calculating the attenuation exponent: true (green dot) and calculated (red dot) visitor position*

Fifty consecutive simulations were implemented to estimate the visitor position. To achieve more realistic results, white noise is added to the $RSSI$ values. The absolute position error range is (1.5 - 7.6) m. The mean error is 3.12m and the root mean square error is 3.89m. 64% of all measurements have position errors below 4m.

4.3.4 BLE beacon filtering algorithm

In order to obtain a reliable estimate of exactly which beacon the visitor is next to, different beacon filtering techniques need to be applied. The beacon filtering algorithm is executed in the following sequence:

1. Only beacons of type iBeacon and with $UUID$, corresponding to the service, are processed. All other BLE packets are ignored.
2. Read the values of $RSSImajor$ and $minor$ for the current beacon. The value of the$major$ field is used as the organization (museum) identifier, with the value of the$minor$ field as the exhibit identifier.
3. If the$major$ value of the current beacon matches theid of an organization (museum) and no information about it is yet displayed, the museum home page is created and displayed.
4. The beacon identifier "$major$-$minor$" is formed. An entry for the beacon with the specified identifier is made in an associative array named beacons. An array$rssi$ is initialized, which will record the signal strength values of the current beacon. This array is cyclic and$N$ consecutive values of $RSSI$ are written to it. The goal is to implement a moving average filter for the values of $RSSI$.
5. Get the average value for $RSSI$: $averageRssi$

$$averageRssi = (\sum_{i=1}^{N} RSSI_i)/N. \qquad (14)$$

   where $RSSI_i$ is the power a of the beacon signal with time index i, and N is the number of analyzed values of $RSSI$.

6. Check the proximity of beacons for which the value of$averageRssi$ is greater than a given threshold value of $RSSI\_THRESHOLD$. If the value of$averageRssi$ is less than or equal to this threshold value, the entry for the current beacon is deleted from the$beacons$ associative array (the beacon is too far away from the visitor) and proceed to point 1. Otherwise, it proceeds to point 7 of the algorithm.
7. Calculate the distance between the beacon and the client based on$averageRssi$ and the path loss exponent. This model describes how the power of the radio signal decreases as it moves away from the transmitter.
8. An object called$beaconData$ is created that contains information about $averageRssi$, the distance to the beacon, and whether the beacon is close to the client (variable $near$). The initial value of $near$ is $false$.
9. Check whether the content associated with the current beacon should be displayed. If the calculated distance to the beacon is less than a threshold value of$dTh1$ and the value of the$near = false$ flag, then it is assumed that the

content should be delivered. In this case, the value of the proximity flag is changed to $true$.

10. If the distance to the beacon becomes greater than the threshold value$dTh2$ and the proximity flag value$near = true$, then the value of this flag is changed to .$false$
11. Save object$beaconData$ to the array $beacons$
12. Transition to 1.

4.3.5 Experiments

The functionality of the proposed content delivery service based on BLE beacons is implemented using a mobile application for Android and iOS operating systems and business logic written in Node.js with a web interface that implements the content delivery system. Google Firebase is used as the file storage server. With the help of this database application, all the necessary collections for two organizations were created: 1) an open-air museum (Ethnographic Museum "Etar") and 2) a department in a university (Department of Computer Systems and Technologies, TU-Gabrovo). BLE beacons of the Anchor Beacon type from the company kontakt.io were used. The following beacon configuration was used to test the service: iBeacon for beacon type; -4dBm for Tx Power and 600ms for data packet sending interval. With this configuration, the beacon battery (2xCR2477) lasts approximately 2 years. The information provided to visitors is related to the Department's laboratories and some of the workshops on the Museum's craft street. The beacons are secured with double-stick tape halfway down the width of the door of the rooms or workshops.

4.3.6 Conclusion

A dynamic content delivery service using BLE beacons of the iBeacons type has been developed. Unlike other similar services that are developed specifically for an organization, the proposed service can be used by multiple organizations. Thanks to the beacon filtering algorithm, the recognition of the object for which content is to be delivered is reliable for both organizations.

The use of BLE beacons in indoor museums is a major challenge as several important issues need to be addressed, e.g. how to attach the beacons, where to deploy them, how to ensure scalability of the application, etc.). Preliminary experiments in simulated and real environments show very good potential for the proposed service.

4.4 Service for delivering content to visitors of outdoor museums via geofencing

Geofencing occupies a key role as a technology for virtually fencing certain geographic areas, through which monitoring and response to users' real-time movement is performed.

The main advantage of geofencing is the ability to send hyperlocal push messages to users upon entering or leaving a specific area. This makes it extremely effective in areas such as mobile marketing, logistics, security and cultural tourism, without the need for specialized hardware on the part of the user. The technology's compatibility with over 90% of today's smartphones ensures wide applicability.

4.4.1 Web service for creating geofences

Within the framework of this thesis, a web-based service has been developed to create, edit and manage geo-fences of varying shape and scope. The aim of the service is to provide a convenient tool for defining geospatial areas that can be used to contextually deliver content to visitors, especially in cultural and outdoor tourism sites.

The system allows the creation of geofences in the form of polygons using GPS maps and satellite imagery through a convenient web interface. The GeoJSON format is used to describe and store spatial objects, compatible with NoSQL databases such as MongoDB.

4.4.1.1 Architecture and technology

The service is implemented as a microservice using:

- Node.js - to execute the server logic.
- Express - for building the REST interface.
- MongoDB Atlas - as a cloud NoSQL database.
- Mapbox GL-JS - for visualizing and interacting with maps;

Through the web interface, users can:

- create new geofences.
- edit existing zones by moving or adding vertices.
- export created geofences to a MongoDB database.

4.4.1.2 Experiments

For testing, eight databases with 50 to 10,000 visitors were created, randomly located in Technical University - Gabrovo. Geospatial operators ($geoWithin, $geoIntersect, $near) were used to measure query times in MongoDB. Without indexing, the execution time grows almost twice as the number of clients doubles, while with 2dsphere indexing it is about 1ms. There is no significant difference between the $geoWithin and $geoIntersect operators in terms of speedup the $near and $nearSphere operators also run under 1ms with 2dsphere indexing.

A Node.js application was developed that visualizes visitor positions in geofences or outside geofences and measures response times, including communication delays. With

5G connectivity, the average delay is about 195ms (maximum 290ms), mainly due to the delay in accessing the database via MongoDB App Service.

4.5 Mobile app for creating and exporting geofences

The mobile app is necessary for precise and interactive management of geo-fences, especially for historical sites that are not clearly visible on standard GPS maps. These sites, such as ruins or partially preserved ruins, have complex and irregular shapes that cannot be accurately modeled with simple circular areas. Therefore, the application allows manual delineation of geofences with polygons, which enables accurate and detailed description of their contours.

The created application allows for easy addition, editing and deletion of points in the polygons, thus ensuring the up-to-datedness and accuracy of the database.

Storing the data in MongoDB in GeoJSON format allows efficient use of geospatial queries to track user movement against these areas.

4.5.1 Application architecture

The application was developed with the Cordova and Framework7 programming framework, using Realm Web for database connectivity and Mapbox GL-JS for GPS map visualization. The user interface is simplified and offers functions for controlling the GPS receiver, selecting the GPS map type, creating and editing polygons, changing names and exporting geofences to the database. Each query to the database requires access authorization.

4.5.2 Experiments

Testing was carried out at the historic Gradiste fortification near Gabrovo, where polygons describing dwellings and a medieval basilica were created and edited in detail using the application, based on reconstructions. The geofences are exported as GeoJSON documents to the database.

The application allows interactive input and editing of polygons on GPS maps, with the user's position displayed in real time, facilitating accuracy through data from historians and archaeologists. Visualization of all geofences is accomplished through a separate application.

4.6 Service to provide an interface to ChatGPT

A microservice has been developed to provide integration with the ChatGPT language model via the GPT API. The solution aims to incorporate generative artificial intelligence into distributed systems with a focus on scalability, resilience and context remembering in communication. The service supports communication via both AMQP protocol (RabbitMQ broker) and REST interface for clients without AMQP support.

The architecture is implemented as a Python microservice. RabbitMQ was chosen because of its high performance (multithreaded request processing). The solution allows for resilient and efficient workload distribution, critical for real-time interaction with users.

The developed service demonstrates the applicability of generative models in microservice systems targeting cultural institutions and educational environments, facilitating personalized communication and interactive content for visitors.

4.6.1 Architecture

Microservice acts as an intermediary between external users and ChatGPT, supporting a mechanism for remembering the context of conversations. The proposed solution follows the principles of microservices and allows horizontal scaling, isolation of functionality and flexible integration into larger systems.

4.6.2 Experiments

The functionality of the developed ChatGPT access microservice was validated through two experiments. In the first test, the performance of the service was analyzed for an individual client using a web interface implemented with Node.js. Conversational context maintenance and response time for single requests were verified, including the ability to restart the context.

In the second experiment, the behavior of the service was measured under high load - 500 requests from 250 different clients. Requests were sent at maximum speed from a console application. The aggregate response time for all requests was 5.6 minutes, with no request loss, demonstrating the robustness and efficiency of the architecture in parallel processing.

4.6.3 Conclusion

A microservice providing a reliable interface to ChatGPT via the AMQP protocol has been developed and tested, allowing easy integration into distributed systems to create chatbots with a generative language model. Experiments conducted demonstrate robust performance even with multiple parallel requests. The interface has been tested with the gpt-4.5-turbo-0614 model and has been successfully used to deliver customized content in outdoor museums.

Conclusions

In Chapter 4, localization technologies (NFC, BLE, geofencing) and their integration with generative artificial intelligence (GPT API) are analyzed in order to dynamically generate personalized content. Algorithms for filtering BLE beacons and adaptively determining the fading exponent are developed to improve the accuracy of the system. Experiments validate the effectiveness of the solutions in simulation and real-world environments.

Conclusion

This dissertation explores the possibilities of implementing personalized content in outdoor museums, focusing on state-of-the-art technologies and innovative approaches. The developed service, based on distributed architecture and microservices, demonstrates the potential of technologies such as GPS, BLE, NFC and artificial intelligence to deliver dynamic and adaptive content tailored to individual visitor interests and behaviors.

The research confirms that the integration of these technologies offers new opportunities for museums to adapt to the demands of the modern digital age. Despite challenges related to data security, technical limitations and the need to balance personalization and privacy, the results show that the implementation of such solutions is feasible and effective.

Future research can focus on deeper integration of artificial intelligence, improving localization accuracy, and extending group interaction functionalities. This will contribute to an even more rich and interactive museum experience that meets the diverse needs of visitors and supports the educational and cultural mission of museums.

DISSERTATION CONTRIBUTIONS

Scientific results:

1. An innovative architecture based on microservices is proposed. It integrates geofencing (GPS/BLE), NFC technologies and artificial intelligence (GPT API). This approach solves key challenges related to scalability, sustainability and efficiency in delivering personalized content in museums. The development of this architecture contributes to the theoretical foundation of cultural heritage management systems and can be adapted to other applications such as tourism and education (Section 2.4).

2. An original algorithm has been developed for personalized museum content delivery that integrates GPS, BLE, NFC and AI technologies with multisensory localization. Key innovations include a multi-layered visitor profiling system (explicit, pseudo- explicit and implicit), intelligent "notification fatigue" recognition and energy efficient sensor management. The algorithm provides dynamic personalized content generation through the integration of generative artificial intelligence (Section 2.5).

3. An innovative visitor segmentation methodology has been developed that combines three approaches: explicit (surveys), pseudo-explicit (OAuth profiling) and implicit (BLE/GPS tracking) methods. The methodology creates dynamic user profiles that adapt in real time. The introduced two-stage model of "initial" and "fine"

segmentation allows incremental refinement of profiles, from basic demographics to detailed behavioral models (Section 3.3).

Scientific and applied results:

1. A methodology for experimental determination of signal attenuation exponent using BLE beacons has been developed. The methodology allows precise calculation of distances between visitors and museum exhibits, which is essential for the quality of personalized service (Section 4.4.3).

2. An iterative algorithm with adaptive weight averaging was created to dynamically determine the attenuation exponent for different areas in a museum environment for visitor localization in the absence of GPS. The algorithm automatically adapts to the specific conditions of each location by selecting the optimal subset of beacons for maximum accuracy (Section 4.4.4).

3. An algorithm has been developed and tested that allows real-time selection of beacons associated with the selected organization that are near a specific visitor. The algorithm enables the development of mobile applications to deliver content to museum visitors through hybrid technologies (Section 4.4.5).

Main applied results:

1. A database in GeoJSON format has been created for the sites of the Ethnographic Open-Air Museum Etar. By using 2dsphere indexing, extremely fast geospatial parsing was achieved - about 1ms to determine the positions of up to 10,000 visitors relative to the geo-sites, providing efficient real-time operation (Section 4.3.1).

2. Dedicated mobile applications with innovative functionalities have been created, including hybrid localization through a combination of GPS, BLE and NFC technologies, delivery of personalized text content through generative artificial intelligence, intelligent power management to optimize battery life, and customized user interfaces adapted to different types of users (Section 2.6, Section 4.3.2, Section 4.4.6 and Section 4.5.2).

3. A minimum viable service business logic product has been developed.

4. A comprehensive system validation methodology including functional, performance and reliability tests has been developed. The methodology allows comprehensive verification of all system components in a controlled environment prior to its actual deployment.

The dissertation makes theoretical and practical contributions to the field of personalized content delivery to museum visitors, proposing innovative solutions that can be applied not only in cultural institutions, but also in other fields related to tourism and education. Successful implementation of the proposed technologies will allow museums to adapt to the demands of the modern digital age and offer unique, engaging experiences to their visitors.

LIST OF PUBLICATIONS ON THE DISSERTATION

[**V1**] Ivanov, R., & **Velkova**, V. (2022). Delivering Personalized Content to Open-air Museum Visitors Using Geofencing. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, *12*, 141-150.

[In *International Scientific Conference UNITECH* (Vol. 1, p. 290).

[V3] Ivanov, R., & **Velkova**, V. (2023). Tangible and Personalized Smart Museum Application. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, *13*, 97-106.

[V4] Velkova, V., & Ivanov, R. (2023, October). Mobile application for creating and exporting geofences. In *2023 International Conference Automatics and Informatics (ICAI)* (pp. 221-224). iEEE.

[V5] Ivanov, R., & **Velkova**, V. (2024, May). microservice-Based Interface to ChatGPT. in *2024 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR)* (pp. 1-5). iEEE.

[V6] Ivanov, R., & **Velkova**, V. (2024). Enhancing Museum Experiences: A Multi-Institution Mobile Multimedia Delivery System Using BLE Beacons. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, *14*, 187-196.

[V7] Velkova,V., (2024) User Segmentation Using Social Media Profiles, Int. Scientific Conf. Unitech, 21-22 November 2024, Gabrovo, https://www.unitech.tugab.bg/archive/unitech-2024/thematic-session/computer-system-and-technologies, https://unitech.tugab.bg/images/2024/dokladi/4.COMPUTER_SYSTEMS_AND_TECHNOLOGIES/USER_SEGMENTATION_USING_SOCIAL_MEDIA_PROFILES.pdf

[V8] Velkova, V. (2024) Mobile App for Content Delivery for Museum Exhibits Using NFC Technology, Int. Conf. INTERNATIONAL SCIENTIFIC CONFERENCE 21-22 November 2024, Gabrovo, https://www.unitech.tugab.bg/archive/unitech-2024/thematic-session/computer-system-and-technologies,https://www.unitech.tugab.bg/images/2024/dokladi/4.COMPUTER_SYSTEMS_AND_TECHNOLOGIES/MOBILE_APP_FOR_CONTENT_DELIVERY_FOR_MUSEUM_EXHIBITS_USING_NFC_TECHNOLOGY.pdf

CITATIONS RELATED TO THE PHD STUDENT'S PUBLICATIONS

Scientific work	Publications in which he has been cited
1. Ivanov, R., & **Velkova**, V. (2022). Delivering Personalized Content to Open-air Museum Visitors Using Geofencing. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, *12*, 141-150.	**1.** Douros, P., Papageorgiou, K., Milioris, K., Panagiotakopoulou, K., & Kaldis, P. (2023). Digital transformation using marketing strategies in cultural organizations and diffusion of knowledge through technology, a systematic literature review. *Transnational Marketing Journal*, *11*(1), 199-216. (SJR = 0.24). **2.** Pattakos, A., Zidianakis, E., Sifakis, M., Roulios, M., Partarakis, N., & Stephanidis, C. (2023). Digital Interaction with Physical Museum Artifacts. *Technologies*, *11*(3), 65 (IF = 4.2) **3.** Perera, P., Webber, S., & Smith, W. (2024, October). Digital design considerations in urban nature. In *Proceedings of the 27th International Academic Mindtrek Conference* (pp. 235-243). **4.** Pilege, E. (2023). Career Guidance Model for Digital Transformation in the Cultural and Creative Industries. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, (XIII), 189-198. **5.** Merighi, R. (2023). La tecnologia Beacon per il miglioramento dell'esperienza museale: Analisi della letteratura e il caso di Ca'Rezzonico.
2. **Velkova**, V., & Ivanov, R. (2022). Microservice for creating geofences. In *International Scientific Conference "UNITECH* (Vol. 1, p. 290).	**6.** Hooda, A., Jain, R., & Jha, A. (2024). mobile phone location-based advertising (MLBA): emergence, premises and future research agenda. *multidisciplinary reviews*, *7*(11), 2024276-2024276.
3. Ivanov, R., & **Velkova**, V. (2023). Tangible and Personalized Smart Museum Application. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, *13*, 97-106.	**7.** Nawawia, A. U., Pantjawatib, A. B., Saripudina, A., Arief, N. F., Hakimc, N., Karostianib, N., & Darmawanb, A. D.. P. (2024). Development of the Android Application for the Landslide Disaster Mitigation Real-time System Based on Firebase Server and OneSignal. *Jurnal Elektronika dan Telekomunikasi (JET)*, *24*(2), 129-136. **8.** Rosser Limiñana, P., & Soler, S. (2024). Quantitative Evaluation of Visitation Dynamics and Audience Segmentation for Sustainable Management of Civil War Memorial Heritage in Alicante, Spain (book chapter).
4. **Velkova**, V., & Ivanov, R. (2023, October). Mobile application for creating and exporting geofences. In *2023 International Conference Automatics and Informatics (ICAI)* (pp. 221-224). iEEE.	**9.** Sasaki, I., Arikawa, M., Lu, M., Utsumi, T., & Sato, R. (2024). Data-Driven Geofencing Design for Point-Of-Interest Notifiers Utilizing Genetic Algorithm. ISPRS International Journal of Geo-Information, 13(6), 174 (IF = 2.8).
5. Ivanov, R., & **Velkova**, V. (2024, May). microservice-Based Interface to ChatGPT. in *2024 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR)* (pp. 1-5). iEEE.	**10.** Jhingran, S., Bansal, N., Chaturvedi, R., Singh, A., & Arora, Y. (2024, December). Decentralized Generative AI Model Deployment Using Microservices. in *2024 International Conference on Artificial Intelligence and Quantum Computation-Based Sensor Application (ICAIQSA)* (pp. 1-5). iEEE.