METHODOLOGY OF COMPARATİVE TEACHİNG OF RASTER AND VECTOR GRAPHİCS İN SECONDARY SCHOOLS

This article examines the comparative teaching methodology of computer graphics specifically raster and vector graphics as an integral part of the informatics curriculum in secondary schools (grades V-IX). Arguing that the conventional, isolated teaching of these two graphic types in textbooks remains merely formal and fails to foster a comprehensive understanding among students, the author proposes a comparative analysis model."

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Key words: Raster graphics, vector graphics, informatics teaching, comparative methodology, visual literacy, digital competencies.

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AI-POWERED INFORMATION SYSTEM FOR VISITOR IDENTIFICATION AND AUTOMATED ACCESS CONTROL IN SPORTS FACILITIES

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Abstract. The article examines the design and formalization process of an information system for tracking visitors in fitness centers based on system analysis methods. A conceptual model of the system is developed, defining its architecture at the levels of a supersystem, external environment, internal subsystems, as well as input and output data flows. A logical-mathematical model is constructed to describe the business logic of user interaction with the mobile application using set theory and Boolean access functions.

A cryptographic algorithm for generating dynamic QR codes with anti-passback protection is proposed to ensure secure access control and prevent repeated entry misuse. An objective function aimed at minimizing client service time at reception during peak hours is formulated. Special attention is given to the practical integration of artificial intelligence technologies, including an intelligent chatbot based on large language models [1, 2] (LLMs) via the OpenAI API for 24/7 user support, as well as predictive analytics modules for forecasting gym occupancy and reducing client churn. The simulation results demonstrate a reduction in visitor identification time and the automation of routine organizational communication processes.

Key words: system analysis, conceptual model, mathematical modeling, mobile application, QR code, anti-passback, artificial intelligence, large language models (LLM), predictive analytics, sport, fitness industry.

Introduction. The current stage of development of the global digital economy is characterized by a large-scale transformation of the service sector, particularly the fitness and wellness industry. The fast-paced lifestyle of consumers and increasing market competition require sports facilities to implement advanced automation tools to improve service quality, optimize internal business processes, and ensure a high level of personal data security.

One of the key challenges faced by most large fitness centers is the occurrence of long queues at access control points (reception areas) during peak hours. Traditional methods of client identification, such as searching by surname in a database, checking paper logs, or using standard plastic membership cards, are outdated, inefficient, and lead to significant time losses for both visitors and staff. Moreover, conventional access control systems are often vulnerable to unauthorized sharing of identification credentials (memberships) with third parties, resulting in financial losses for the business.

An effective solution to this problem is the development and implementation of specialized software in the form of a mobile application that integrates dynamic verification technologies (e.g., short-lived QR codes with anti-passback protection algorithms). At the same time, the modern trend in information systems development requires interface intelligence. The integration of artificial intelligence technologies, in particular large language models (LLMs) [3] via application programming interfaces (APIs), enables not only the automation of access control processes but also provides users with 24/7 personalized support, thereby reducing routine communication workload for managers.

The transition from a conceptual idea to a reliable software product requires strict formalization of processes based on system analysis and mathematical modeling methods. Describing business logic using set theory, logical conditions, and objective functions ensures algorithm correctness, optimizes database architecture, and minimizes overall client service time.

The aim of the research is the system analysis, conceptual and mathematical modeling of an information system for tracking fitness center visitors in the form of a mobile application integrated with artificial intelligence technologies, in order to minimize customer service time and automate the business processes of a sports facility.

Research implementation. The development of any modern software system, in particular a mobile application for tracking gym visitors, requires the application of system analysis methods. The first and most important step in this process is the construction of a conceptual model. A conceptual model allows one to abstract from specific technical implementation details and focus on the essence of the system: its components, the relationships between them, and its interaction with the external environment. Previous studies on the construction of conceptual models of information systems were analyzed in works [4, 5, 6].

From a systems perspective, a mobile application is not merely an isolated program on a user's smartphone, but an integral part of a complex socio-technical system operating within a specific business environment. In accordance with the principles of information system modeling, the developed conceptual model includes the following key levels: a supersystem, the external environment, the information system itself (with its internal subsystems), as well as input and output data flows [7].

The supersystem for the project is the digital economy and the fitness and wellness industry. It includes global trends in service digitalization, electronic payment infrastructure, as well as the regulatory framework (in particular, personal data protection laws such as the GDPR or the Law of Ukraine «On Personal Data Protection» [8]).

The external environment directly surrounds the system and defines the conditions of its operation. In this case, it is the overall management system of the sports facility. The external environment also includes external actors (entities) that directly interact with the system but are not part of its internal structure:

1. Clients (generate the primary demand and use the mobile application to generate QR codes and view their balance).
2. Gym owners (act as the primary stakeholders and end users of the system's analytics; they make managerial decisions based on the data provided by the system).
3. Payment systems (external services that enable membership payments, provided that such a module is implemented).
4. Cloud service providers (companies that supply server infrastructure to ensure the continuous operation of the application's database).

Any system acts as a transformer of input information into output information. The primary input to the system is a «Request for gym visit». Physically, this occurs when the client opens the mobile application, generates a unique QR code [9], and presents it to the scanner at the reception desk. Additional input data includes requests for new user registration, subscription plan changes, or the purchase of a new membership. The result of successful processing of an input request is a «Recorded visit». The consequences of this output include the automatic deduction of one training session from the client's balance (or the recording of a visit day for unlimited memberships), the opening of the turnstile (or administrative approval for entry), as well as the updating of statistical data in the database.

To ensure the fulfillment of its functions, the developed system is decomposed into four main interrelated subsystems (clusters), each performing a specific role.

The «Mobile application» subsystem is the frontend part of the system with which the client directly interacts. Its main components include:

- user interface (a graphical shell designed according to principles of ergonomics and usability);
- registration / authentication module (responsible for secure system access via phone number, email, or device biometrics);
- electronic membership pass (a key component that generates a dynamic QR code to prevent sharing with third parties, e.g., via screenshots);
- visit history (a section where clients can track their activity and remaining services).

The «IT Infrastructure» subsystem is the backend part and core of the system, responsible for processing and storing all data:

1. Database (a relational or NoSQL database where user profiles, subscription types, visit logs, and transaction records are stored).
2. Validation system (a server-side module that instantly verifies the scanned QR code, matches it against the database, checks for an active subscription, and makes an access decision).
3. API gateway (ensures secure data exchange between the mobile application, reception scanners, and the database).

The «Physical Environment» subsystem is designed as a software product that is inseparable from the physical environment in which it is used:

- reception (the location where the QR code is physically scanned via the administrator's tablet/smartphone camera or a stationary scanner);
- gym workout areas and group training zones (the endpoints that the client gains access to after a successful check-in).

The «Staff» subsystem cannot function without the people who operate and maintain it:

1) reception administrators (directly interact with the system interface to control access, resolve conflict situations – e.g., if a client's phone is discharged, and sell new memberships);

2) trainers (may use the system to verify client registrations for personal training sessions);

3) technical support and developers (ensure the stability of the IT infrastructure and release updates for the mobile application).

All described subsystems are closely interconnected. The client initiates the process through the mobile application, which communicates with the IT infrastructure to obtain a token (QR code). The client then presents this code at the reception, where the administrator or an automated scanner sends a verification request back to the database. After the request is approved, the system records the visit, and the results of this transaction become available to the gym owner in the form of managerial reporting.

A visual representation of the described conceptual model of the gym visitor management information system is shown in Fig. 1.

The presented conceptual model serves as a fundamental basis for the further formalization of the system's mathematical model. It clearly defines the project boundaries, identifies the set of input parameters and desired output results, and establishes logical relationships between software modules, the physical environment, and the people interacting with the system.

The transition from the conceptual model to direct software development requires strict formalization of processes. The mathematical model of the gym visitor management mobile application allows the system's business logic to be described using set theory, functions, and logical conditions. This ensures that the algorithms underlying the software implementation operate correctly, avoid contradictions, and provide reliable data protection [10].

To construct the mathematical model, let us identify the main objects of the domain and represent them as sets.

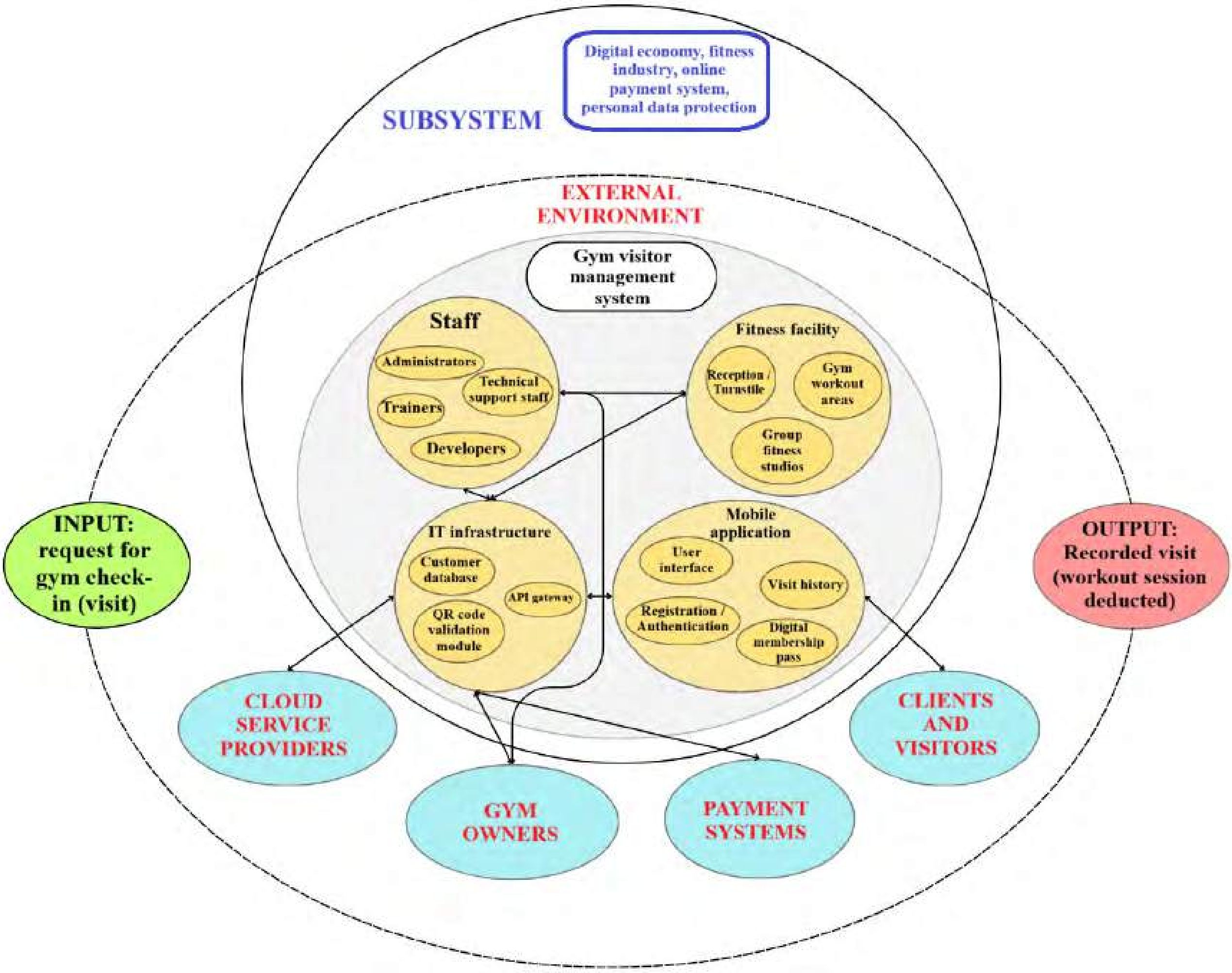

Figure 2. Conceptual model of the mobile application information system

Let us define the basic sets of the system:

1. $C = \{c_1, c_2, \ldots, c_n\}$ – the set of registered clients (application users), where n is the total number of gym clients.

2. $S = \{s_1, s_2, \dots, s_m\}$ – the set of available subscription types (e.g., single entry, 10-session pass, unlimited monthly membership, etc.), where m is the number of pricing plans.

3. $A = \{a_1, a_2, \dots, a_k\}$ – the set of active or purchased memberships associated with specific clients.

4. $V = \{v_1, v_2, \dots, v_p\}$ – the set of recorded visits stored in the database.

Each client $c_i \in C$ x is characterized by a unique identifier (ID), which is used to generate an electronic access key. Each purchased membership $a_j \in A$ has a set of mandatory numerical and temporal parameters:

1. $D_{exp}(a_j)$ – expiration date of the membership.
2. $N_{total}(a_j)$ – total number of training sessions included in the plan.
3. $N_{rem}(a_j)$ – remaining number of sessions in the current balance.
4. $Status(a_j)$ – current membership status, which takes values from $\{0, 1\}$, where 1 means «active» and 0 means «inactive» (frozen or expired).

The core of the mobile application is the generation of a dynamic QR code for contactless entry (check-in). To prevent clients from sharing screenshots of their QR codes with third parties, the code must change dynamically. Let us formalize the QR code generation function $Q(c_i, t)$:

$$Q(c_i, t) = Hash(ID(c_i) + t + Key), \tag{2.1}$$

where $Hash()$ is a cryptographic hash function; $ID(c_i)$ – is the unique identifier of the client; t – is the current timestamp (Timestamp) with second-level precision; Key is a secret server-side key that ensures protection against forgery.

Thanks to the parameter t, he generated QR code remains valid only for a short period of time (for example, 30 seconds), after which the application automatically generates a new code.

When a client presents a smartphone with a QR code to the administrator's scanner, the system must instantly decide whether to grant access. Let us define a Boolean access function $Access(c_i, t_{scan})$, which returns 1 (access granted) or 0 (access denied).

The access function takes the value 1 if and only if all of the following logical conditions (constraints) are simultaneously satisfied:

$$Access(ci, tscan) = 1 \Leftrightarrow \begin{cases} Status(a_j) = 1 \\ t_{scan} \le D_{exp}(a_j) \\ N_{rem}(a_j) > 0 \\ (t_{scan} - t_{last}) > \Delta T_{min} \end{cases}, \tag{2.2}$$

where $Status(a_j) = 1$ – ensures that the client's membership is not frozen and is active in the system;

$t_{scan} \le D_{exp}(a_j)$ – ensures that the current scan time does not exceed the membership expiration date, meaning the membership is still valid in terms of time;

$N_{rem}(a_j) > 0$ – ensures that at least one unused training session remains on the client's balance (this condition is ignored for unlimited memberships, where $N_{rem} = \infty$);

$(t_{scan} - t_{last}) > \Delta T_{min}$ – provides anti-passback protection against repeated triggering of the same access event.

The difference between the current scan time and the time of the last successful visit (t_{last}) must be greater than the minimum allowed interval ΔT_{min} (for example, 60 minutes). This prevents situations where one client passes through the turnstile and then hands the phone over the fence to a friend, who scans the same code again.

This prevents situations where one client passes through the turnstile and then hands the phone over the fence to a friend, who scans the same code again:

$$N_{rem}^{new}(a_j) = N_{rem}^{old}(a_j) - 1 \tag{2.3}$$

Formula (2.3) implies that after each successful entry, the number of available sessions is reduced by one. Information about the deduction is instantly sent via API to the client's mobile device, and the user interface is updated accordingly.

The main problem addressed by the implementation of the developed application is queues at the reception desk and inefficient use of staff time. Therefore, the overall goal of the software development can be formulated as a mathematical problem of minimizing service time.

Let $T_{service}^{i}$ – denote the time required for identification and access processing of a single (i-th) client. Using traditional methods (surname lookup, paper log verification), this time consisted of search time T_{search}, verification time T_{check} and manual record entry time T_{write}:

$$T_{service\_old}^{i} = T_{search} + T_{check} + T_{write} \tag{2.4}$$

When using the mobile application with a QR code, the process is reduced to only the hardware scanning time T_{scan} and the server response time T_{server}:

$$T_{service\_new}^{i} = T_{scan} + T_{server} \tag{2.5}$$

he project's objective function is to minimize the total waiting time ΣT for the entire flow of visitors C_{peak} during peak load periods:

$$F = \sum_{i=1}^{C_{peak}} \left(T_{scan}^{i} + T_{server}^{i}\right) \to \min \tag{2.6}$$

To achieve the optimum of the objective function (2.6) during the software development stage, the following requirements must be satisfied:

- optimize the database structure (use indexing for the clients table) so that the server response time T_{server} approaches its minimum value ($T_{server} \leq 0{,}5$ sec);
- develop a lightweight and fast scanner interface for the administrator that minimizes the scanning time T_{scan}.

Thus, the developed mathematical model formalizes all key visitor tracking processes. It clearly describes the logic of granting access to the gym, the rules for updating membership balances, and defines the system's efficiency criterion.

The main objective of the developed logical access model is to minimize the time a client spends at the reception desk. Let us consider a practical example of system operation during peak load, such as at 6:30 p.m. on a weekday, when a large number of visitors arrive at the gym simultaneously. The client, approaching the access control area, opens the mobile application, after which the system generates a dynamic QR code based on the user’s unique identifier and the current timestamp. By holding the smartphone screen up to the reception scanner or directly to the turnstile, the client initiates data capture, which occurs within fractions of a second. The encrypted request is then transmitted to the server [11].

On the server side, the previously described logical access function is triggered instantly. The system sequentially verifies the validity of the scanned code, since its lifetime is limited to thirty seconds, any attempt to gain access using a screenshot is automatically rejected. In parallel, the system checks membership activity, the availability of remaining sessions on the user’s balance, and compliance with the anti-passback rule, which blocks repeated scanning of the same code within the next hour. This mechanism prevents situations where a single membership is used simultaneously by multiple individuals. If all checks are successfully passed, the system returns a positive response: the turnstile opens, one training session is automatically deducted from the user’s balance, and the visit is immediately recorded in the attendance history. Thanks to this optimization, the overall service time per client is reduced from one to two minutes with manual lookup to just two to three seconds, completely eliminating queues and allowing reception staff to focus on customer service and sales.

The developed application incorporates the integration of artificial intelligence technologies through the implementation of an intelligent chatbot based on large language models, in particular via the OpenAI API. The assistant is implemented as a floating button located in the lower-right corner of the screen; when pressed, it opens a chat window for natural language communication.

The practical application of artificial intelligence within the application covers several functional areas. The first is intelligent 24/7 customer support, where instead of calling an administrator, the client can receive an immediate response regarding the schedule, membership freezing rules, or group class timetable. The AI model, preconfigured via system prompts to match the specifics of a particular gym, generates accurate and relevant answers.

The second area is personalized recommendations based on data. With access to anonymized visit history, the artificial intelligence can proactively suggest additional classes or reminders for recovery, creating the effect of a premium personalized service. The third area is assistance in the training process, where the built-in chatbot acts as a pocket reference, providing safe recommendations regarding exercise technique or warm-up selection based on verified fitness databases.

The implementation of artificial intelligence not only increases user engagement with the application but also reduces up to forty percent of routine communication workload for reception administrators and sales managers. Data collected through the mathematical model of visit tracking forms a dataset that can be used by gym management to make informed managerial decisions. The integration of data analysis algorithms enables predictive analytics to be implemented as a fully functional component of the system.

A visual representation of the user interaction logic with the application is shown in Fig. 2.

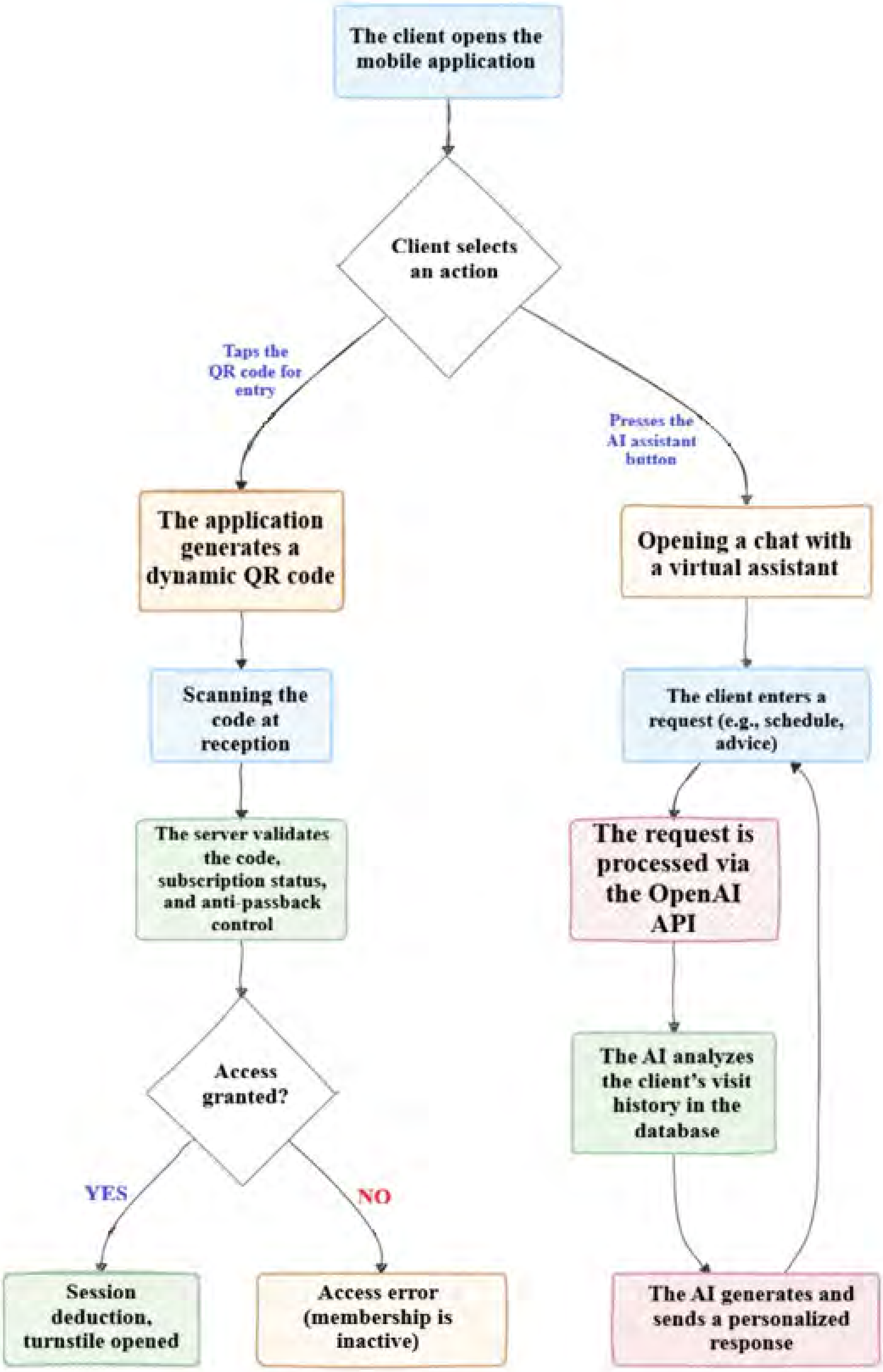

Figure 2. Diagram of user interaction with the access control module and AI assistant

The system continuously analyzes visit frequency and automatically flags clients who have not visited for more than fourteen days as being at risk of churn, sending them personalized push notifications for proactive retention and improved lifetime value (LTV). In parallel, the analytics module predicts gym occupancy based on historical data and the day of the week, enabling staff schedule optimization and preventing staffing shortages during peak hours. In this way, the combination of the developed mathematical models and artificial intelligence technologies transforms the application into a comprehensive ecosystem that automates access control, delivers personalized services, and provides management with tools for business analysis and scaling.

Thus, the presented examples demonstrate the high viability and practical value of the designed algorithms and models. The defined system behavior fully aligns with the project objectives and establishes a foundation for detailed database design and graphical user interface development.

Conclusion. In the course of the conducted research, system analysis methods were successfully applied to develop a comprehensive conceptual model of an information system for tracking visitors in fitness centers. Through a clear decomposition of the system into a supersystem, external environment, and internal clusters («Mobile application», «IT infrastructure», «Physical environment», «Staff»), it was possible to abstract away from technical details and precisely define the project boundaries. This approach enabled the establishment of stable logical relationships among all stakeholders and software-hardware components of the business environment, forming a solid foundation for further system design.

Based on the developed conceptual structure, a strict formalization of business processes was carried out using set theory and logical-mathematical conditions. The proposed Boolean access function and the cryptographic algorithm for generating dynamic QR codes effectively address the security challenge, fully eliminating the risk of unauthorized entry via screenshot sharing or multiple-person use of a single membership, thanks to the integration of an anti-passback mechanism. Mathematical modeling of the objective function demonstrated strong practical value, showing the potential to drastically reduce client identification time at reception to just a few seconds, thereby completely eliminating queueing issues during peak hours.

An additional innovative direction in the system's design is the integration of artificial intelligence technologies and data analytics. The implementation of an intelligent chatbot based on large language models (LLMs) via the OpenAI API, along with predictive analytics modules, not only reduces routine staff workload by up to forty percent but also provides management with tools for forecasting facility occupancy and proactive client retention. Thus, the developed model transforms the mobile application into a comprehensive and viable ecosystem that optimizes access control, enhances the business efficiency of sports facilities, and creates conditions for further scalability.

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