Personalized Recommendations in Smart Campuses

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***Abstract*—Smart Campuses offer a wide array of digital services, academic opportunities, and social initiatives. However, students often face difficulty in making informed academic decisions due to fragmented information and the lack of personalized, context-aware support. Traditional recommendation systems in educational settings typically rely on user profiles and academic history, overlooking the potential of integrating dynamic environmental data. In this work, we introduce a novel recommendation framework that combines user-derived information, such as course records, satisfaction scores, and expressed interests, with cyber-physical campus signals, including classroom availability, mobility flows, and contextual usage patterns. Our approach leverages a hybrid architecture based on Transformer encoders and Graph Neural Networks to capture both semantic similarities and relational structures among users, courses, and campus activities. This integration enables personalized and timely suggestions for course planning, study group formation, and alignment with research interests. By bridging behavioral and environmental contexts, the system aims to reduce decision fatigue, promote student engagement, and enhance academic planning in data-rich educational ecosystems.**

***Index Terms*—Smart Campus, IoT, Hybrid Recommender Systems, Personalized Services, Context Awareness**

I. Long Abstract

Advancements in pervasive technologies and the growing integration of artificial intelligence are driving a transformative evolution in intelligent environments, enabling systems to adapt dynamically, respond promptly, and place users at the center of their operations [1]. Within this context, university campuses [2] emerge as ideal microcosms of smart cities, complex ecosystems where digital services, contextual data, and smart infrastructure converge to enhance the academic experience and optimize operational management [3]. The notion of a Smart Campus [4] extends well beyond mere facility monitoring, aiming instead at deep integration between the physical and digital realms to deliver personalized services to students, faculty, and administrative staff [5].

Despite numerous existing solutions in the Smart Campus domain, many face significant limitations in delivering truly personalized experiences [6]. Predominantly focused on infrastructure management or administrative efficiency, these approaches often overlook the diverse and evolving needs of users. In environments characterized by continuous and heterogeneous information flows, the absence of adaptive, user-centric mechanisms can hinder effective decision-making and lead to suboptimal resource utilization. Moreover, the vast potential inherent in heterogeneous data streams, from mobile devices, IoT sensors, and user interactions within the campus, often remains underexploited [7]. Addressing these challenges is crucial to evolving educational environments into models that are not only efficient but also deeply responsive to individual needs.

This work proposes a novel framework for an enhanced intelligent university environment. The solution hinges on a hybrid recommendation system that combines natural language processing techniques with graph-based models. This synergy enables the generation of personalized, context-aware suggestions concerning academic resources, available campus services, and social engagement opportunities. The system adopts a distributed cloud-edge paradigm, performing preliminary data processing at the network edge close to data sources, while delegating more computationally intensive analyses to scalable cloud infrastructures. This multilayered approach ensures low-latency responses alongside the flexibility to incrementally integrate advanced functionalities.

At the core of the framework lie two advanced recommendation engines. The first leverages Transformer architectures [8] to extract deep semantic representations of students' academic trajectories, identifying meaningful sequential patterns in their learning activities. The second is grounded in graph-based models [9] that capture and exploit the intricate social and academic relationships among users, facilitating the formation of study groups and collaborative environments. By integrating these complementary approaches, the system supports a broad spectrum of services, ranging from highly personalized academic advice to recommendations fostering community engagement.

This work pursues three primary objectives: (i) designing a modular and scalable architecture capable of integrating heterogeneous data sources spanning physical environments and user-generated information; (ii) developing robust recommendation strategies that accommodate individual preferences and group dynamics; and (iii) validating the system's effectiveness through realistic use cases and pilot deployments.

The proposed architecture (Fig. 1) delivers a comprehensive solution for providing personalized, context-sensitive recommendations within a smart campus. It integrates heterogeneous data streams from environmental sensors, personal devices, and academic records into a unified system that feeds sophisticated recommendation engines aimed at supporting both individual guidance and group-based initiatives. The architecture is organized into three main layers: Data Acquisition, Embedding Generation, and Recommendation Engine.

The *Data Acquisition layer* continuously collects raw in-

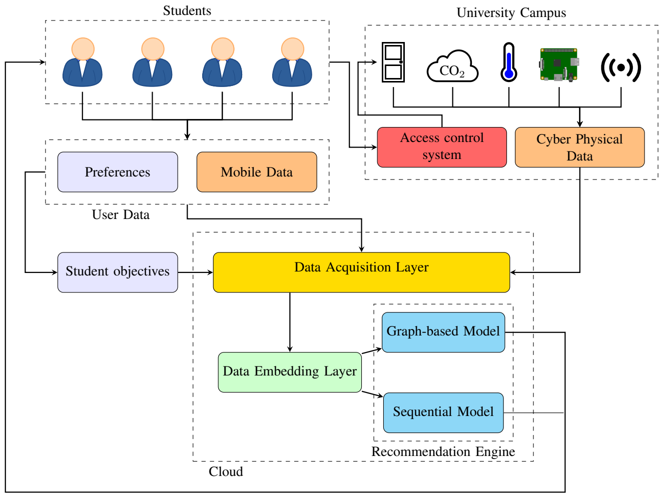

Fig. 1. System Architecture of the Proposed Recommendation Framework Integrating User Profiles, Academic Records, and Cyber-Physical Contextual Signals.

formation from diverse sources distributed across the campus. Environmental sensors monitor parameters such as occupancy, lighting conditions, and air quality; IoT devices and access control systems provide data on communal space usage. Simultaneously, personal devices (smartphones, wearables) contribute positional, behavioral, and preference data, while academic records, including course outcomes, feedback, and participation metrics, build detailed user profiles. These complementary, diverse data streams form a comprehensive representation of the environment and user behavior, transmitted securely to ensure privacy protection.

Subsequently, the *Embedding Generation layer* processes the acquired data through normalization, fusion, and feature extraction pipelines within cloud infrastructures designed for large-scale multimodal data handling. Raw inputs related to users, environment, and points of interest are transformed into dense vector representations within a shared latent space. For instance, student profiles derived from academic and survey data are embedded as continuous vectors capturing personal interests and educational trajectories. Descriptive texts of courses, thesis proposals, and study groups are processed using pre-trained language models to generate semantic embeddings that synthesize content and context. These representations are aligned to provide an integrated data foundation supporting recommendation tasks. The *Recommendation Engine*, the system's core, exploits these embeddings to generate personalized suggestions across multiple domains. It consists of two primary modules operating in parallel. The first employs a bipartite graph model representing students and study groups as nodes. This module dynamically integrates multiple signals, content similarity, historical interactions, and real-time contextual data (e.g., availability, location), to compute compatibility scores, enabling optimal group formation or the initiation of new groups when demand thresholds are exceeded.

Concurrently, the second module leverages sequential models based on bidirectional Transformer architectures to predict subsequent academic steps such as course selection or thesis topics aligned with the student's evolving profile. By analyzing completed course sequences enriched with positional and contextual information, the model constructs detailed representations of academic pathways, enabling the selection of recommendations closely matching individual interests and developmental trajectories. The combination of graph-based and sequential modeling approaches enhances recommendation precision and offers complementary perspectives supporting both personal progression and peer collaboration.

In conclusion, the proposed framework offers an innovative contribution to the development of intelligent university environments that dynamically adapt to individual student needs while fostering collaboration and informed decision-making. By integrating cyber-physical data with hybrid recommendation models, the system delivers real-time, personalized, and context-aware services that enhance the academic experience and overall campus life. Preliminary experiments conducted through realistic usage scenarios demonstrate the effectiveness and adaptability of the approach in supporting both individual and community-oriented services. Thanks to its modular and scalable architecture, the framework is well-suited for future extensions to other educational or urban domains, paving the way for user-centric digital ecosystems that fully leverage the informational richness of smart environments.

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