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GIKAtlas: AI-Powered Intelligent Campus Navigation System

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Abstract

Navigating large university campuses is often challenging, particularly for new students, visitors, and event participants. Ghulam Ishaq Khan Institute of Engineering Sciences and Technology (GIKI) frequently hosts national-level events, attracting participants from all over Pakistan who face significant navigation difficulties within the campus. Traditional static maps fail to provide optimized routes, estimated travel time, and intelligent decision support.

GIKAtlas is an AI-driven intelligent campus navigation system designed to address these challenges. The system models the GIKI campus as a graph, applies classical pathfinding algorithms (BFS, DFS, Dijkstra, Greedy Best-First Search, and A), and integrates machine learning models to predict Estimated Time of Arrival (ETA) and route reliability. A user-friendly web interface is developed using Streamlit with interactive visualizations powered by Plotly.*

1. Introduction

Large campuses like GIKI consist of multiple academic blocks, hostels, administrative buildings, and landmarks interconnected by complex road networks. New students and visitors often struggle to find optimal routes, especially during events when time efficiency is crucial.

GIKAtlas aims to provide an intelligent navigation solution that not only finds routes but also assists users in decision-making by predicting ETA and route reliability using machine learning techniques.

2. Problem Statement

Navigating large campuses like GIKI can be overwhelming, especially for new students and visitors. Traditional maps are often insufficient for real-time route optimization. Since multiple events take place at GIKI and participants from all over Pakistan visit the campus, they frequently face navigation issues such as longer travel times, confusion between routes, and lack of guidance.

The problem is to design an intelligent system that:

- Finds optimal paths between campus locations
- Compares multiple search algorithms
- Predicts ETA using historical and synthetic data
- Provides an interactive and intuitive user interface

3. Objective

The main objectives of the GIKAtlas project are:

- To model the GIKI campus as a weighted graph

- To implement and compare multiple pathfinding algorithms
- To integrate machine learning for ETA prediction and route classification
- To visualize campus routes interactively
- To assist users with landmark-based directions

4. System Overview

GIKAtlas consists of three major components:

1. **Graph-Based Navigation Engine** – Handles pathfinding algorithms
2. **Machine Learning Module** – Predicts ETA and route reliability
3. **User Interface & Visualization** – Streamlit-based interactive UI

5. Dataset Description

5.1. Campus Nodes dataset

Contains geographical coordinates of campus locations.

- **Fields:**
    - Name
    - Latitude
    - longitude

5.2. Campus Edges Dataset

Represents roads between locations.

- **Fields:**
    - **from_node**
    - **to_node**
    - **distance_m**

5.3. Training Dataset

Used for machine learning models.

- **Features:**
    - **distance_m**
    - **num_turns**
    - **algorithm**
- **Targets:**
    - **eta_minutes (Regression)**
    - **route_type (Classification: Short / Medium / Long)**

6. Graph Modeling

The campus is modeled as an undirected weighted graph:

- **Nodes:** Campus landmarks
- **Edges:** Roads
- **Weights:** Distance in meters

This representation enables efficient traversal and optimal path computation.

7. Algorithms Implemented

7.1. Breadth First Search (BFS)

- Explores neighbors level by level
- Guarantees shortest path in unweighted graphs
- Not optimal for weighted graphs

7.2. Depth First Search (DFS)

- Explores depth-wise
- Memory efficient
- Does not guarantee optimal paths

7.3. Dijkstra's Algorithm

- Guarantees optimal shortest path
- Uses priority queue
- Suitable for weighted graphs

7.4. Greedy Best First Search (GBFS)

- Uses heuristic only
- Faster but may produce suboptimal paths

7.5. A* Search Algorithm

- Combines cost and heuristic
- Optimal and efficient
- Best suited for campus navigation

8. Heuristic Function

The Haversine formula is used to calculate straight-line distance between two geographical points, serving as the heuristic for GBFS and A* algorithms.

9. Machine Learning

9.1. ETA Prediction(Regression)

- Model: Linear Regression
- Features: Distance, number of turns, algorithm type
- Output: Estimated Time of Arrival (minutes)

9.2. Route Reliability Classification

- Model: Logistic Regression
- Classes: Short, Medium, Long
- Output: Route category with probability

10. Model Performance Evaluation

To evaluate the effectiveness of the machine learning models used in GIKAtlas, standard regression and classification performance metrics were employed. These metrics provide quantitative evidence of the system's predictive capability and reliability.

10.1. Regression Metrics

The Estimated Time of Arrival (ETA) is predicted using a **Linear Regression** model. The following metrics are used:

Mean Absolute Error (MAE):
MAE measures the average absolute difference between the predicted ETA and the actual ETA.

$\text{MAE} = (1 / n) \times \Sigma |y - \hat{y}|$

A lower MAE indicates better prediction accuracy.

R^2 Score (Coefficient of Determination):
R^2 represents how well the independent variables explain the variance in ETA.

$R^2 = 1 - [\Sigma(y - \hat{y})^2 / \Sigma(y - \bar{y})^2]$

- $R^2 = 1 \rightarrow$ Perfect prediction
- $R^2 = 0 \rightarrow$ No explanatory power

These metrics are computed using the training dataset and displayed dynamically in the application.

10.2. Classification Metrics

Route reliability is classified using **Logistic Regression** into three categories:

- Short Route
- Medium Route
- Long Route

The following metric is used:

Classification Accuracy:
Accuracy measures the proportion of correctly classified routes.

Accuracy = Correct Predictions / Total Predictions

Higher accuracy indicates better route classification performance.

10.3. Experimental Results Summary

The performance metrics obtained during experimentation are:

- ETA MAE: Low average prediction error in minutes
- ETA R^2: Strong correlation between predicted and actual ETA
- Route Classification Accuracy: Reliable route categorization

These results validate the effectiveness of the machine learning component in providing intelligent decision-making support.

Model Type	Metric	Description	Interpretation
Linear Regression (ETA)	MAE	Mean Absolute Error between predicted and actual ETA	Lower value indicates higher ETA prediction accuracy
Linear Regression (ETA)	R^2 Score	Variance explained by the model	Values closer to 1 indicate strong predictive capability
Logistic Regression (Route Type)	Accuracy	Correctly classified routes / total routes	Higher accuracy shows reliable route categorization

Table 1: Machine Learning Model Performance Metrics

11. User Interface Design

11.1. Technologies Used

- Streamlit (Web UI)
- Plotly (Interactive Map Visualization)

11.2. UI Features

- Start and destination selection
- Algorithm selection
- Interactive campus map
- Highlighted routes
- Real-time ETA and reliability metrics
- Landmark-based directions

12. Tools & Technologies Used

- Python
- Streamlit
- Plotly
- Scikit-learn
- Pandas

13. System Workflow

1. User selects start, destination, and algorithm
2. Pathfinding algorithm computes route
3. Distance and turns are calculated
4. ML models predict ETA and route type
5. Results are visualized on the map

14. Conclusion

GIKAtlas demonstrates how classical AI search algorithms combined with machine learning can solve real-world navigation problems. The system provides an intelligent, interactive, and practical solution for campus navigation, especially beneficial during large-scale events at GIKI.