

Shortest Path Navigation Optimization using Algorithm A* in GPS-Based Augmented Reality Visualization

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Abstract

The development of digital technology in the Society 5.0 era encourages the integration of technology-based solutions in various fields, including higher education. Ibnu Sina University faces challenges in providing informative and accurate access to campus navigation, especially for new students and visitors. The lack of a directional system and the absence of a digital map of the campus cause difficulties in finding service locations such as the rectorate, academic room, or finance department. Conventional technologies such as *Google Maps* have not been able to provide specific navigation in the campus environment due to the limitations of internal building mapping. This research aims to develop a campus navigation system based on *Augmented Reality (AR)* and *Global Positioning System (GPS)* that is optimized with the A* (A-Star) algorithm for the determination of the shortest path. AR technology is used to display visual directions in real-time in a real environment through a smartphone camera. GPS plays a role in determining the user's position, while the A* algorithm calculates the shortest route based on the structure of the campus location graph using a *heuristic approach*. The development method used is the *Multimedia Development Life Cycle (MDLC)* which consists of six stages: *concept, design, material collecting, assembly, testing, and distribution*. Data collection was carried out through direct observation, interviews with the campus, and recording 14 coordinate points of campus service locations using *Google Earth*. The system is built using the *Unity platform* with support from the *AR Foundation* and *ARLocation*, as well as the A* implementation in route search. The results of this research are able to provide a more efficient, accurate, and interactive campus navigation solution. This system not only supports the convenience of users in finding a location, but also becomes an innovation in the development of campus services based on digital technology.

Keywords: Campus Navigation, *Augmented Reality*, *GPS*, Algorithm A*, *MDLC*.

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1. Introduction

The development of the global industrial era has entered the phase of Society 5.0, which integrates intelligent technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) to solve various social problems, in the fields of visual inspection, control and automation, calibration and others [1]. In Indonesia itself, the industrial revolution 4.0 and the concept of Society 5.0 began to be adopted in various sectors, including higher education [2]. One of them is the existence of technology-based learning innovations that make it easier for us to learn without knowing space, time and place [3]. Ibnu Sina University as a higher education institution, is required to transform digitally to improve academic services and ease of access to information for students and campus visitors.

As the number of students increases and the complexity of the campus building layout, challenges arise in terms of navigation and finding locations for

campus services such as academic, financial, and faculty rooms. The current manual guidance systems or plan boards are not able to meet the needs of location information quickly, accurately, and in real-time. Therefore, it requires navigation solutions that are adaptive, interactive, and integrated with the latest technology.

Navigation is the process of determining the position or direction of travel in the real world or a map [4]. One of the approaches used is indoor navigation with a *Wi-Fi Positioning System* that utilizes signal triangulation from the transmitter (*router*) to the user's device. However, satellite systems such as GPS do not work optimally in closed areas, so other technology-based alternatives are needed [5].

One promising innovative solution is the use of *Augmented Reality (AR)* technology, which is a technology that combines 3D virtual objects into the real world and allows interaction in real-time [6]. The current use of AR has extended to various sectors due

to its ability to provide engaging, intuitive, and interactive experiences [7]. AR works by combining computer vision and image processing technology, which allows the search for information directly from the user's surrounding environment.

Various studies have shown that the integration between *Augmented Reality (AR)* and *GPS* is able to increase the effectiveness of navigation systems. AR provides visualization of virtual objects in the real world, allowing direct directional guidance through a smartphone's camera device [6]. Meanwhile, GPS provides the accuracy of the user's geographical position in real-time. This technology has been applied in a variety of fields, including Education, transportation, and tourism [8] [9] [10].

In the campus environment, several institutions such as UIN Sunan Ampel Surabaya and Kanjuruhan University Malang have developed AR-based navigation systems to make it easier for students to find locations [11] [12]. However, most of those implementations have not integrated route optimization algorithms such as A* (A-Star), which have been proven to be able to efficiently determine the shortest path through a heuristic approach [13]. The search for the shortest path can be adjusted to the point of the must-pass, and assuming all the weights of the graph are positive, the optimal route can be obtained systematically [14].

To develop such an AR-based system in a structured manner, the *Multimedia Development Life Cycle (MDLC) method* is used because it is suitable for the development of interactive multimedia applications [15]. In addition to visualization, an important component of the navigation system is the determination of the best route. This research integrates the A* algorithm as a fast and efficient shortest path search solution [16].

By using A*, the path search process becomes more efficient and directed because it considers the direction of the destination from the beginning [17]. A* is considered very suitable for GPS-based navigation in AR because it is able to provide results with minimal search time [18]. The shortest path search is not only limited to one point to another, but can also be adjusted to certain conditions such as the point that must be passed [14]. Assuming all the weights of the graph are positive, Then a systematic approach can be carried out to get optimal route results.

The main gap from previous research lies in the optimal use of the shortest path search algorithm. This can be seen based on the lack of comprehensive integration between AR, GPS, and A* algorithms in one real-time and responsive campus navigation system. This study proposes an AR-GPS-based navigation system with an A* algorithm that is able to provide visual direction guidance and determine the

optimal path from the user's location to the campus service point automatically. The contribution of this research presents the convenience of finding and finding campus service locations quickly and accurately.

2. Methods

This research was compiled to describe the flow of systematic stages in developing campus navigation applications based on *Augmented Reality (AR)*, *GPS*, and A* algorithms.

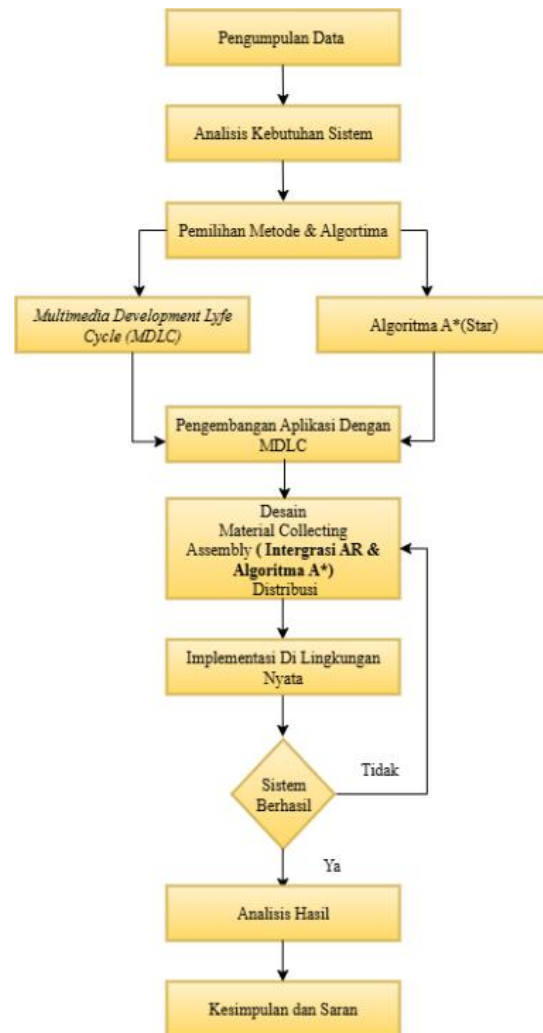


Figure 1. Research Framework

Data collection is carried out in several stages:

Primary data through direct observation to document campus buildings and service points, as well as interviews with Vice Chancellor II and the Head of the Student Affairs Bureau to find out the needs and problems of campus navigation.

Secondary Data is in the form of GPS coordinates for each service point (*latitude, longitude, altitude*) obtained from Google Earth, as well as literature studies related to AR, GPS, and A* algorithms. The

data is used to construct a location graph, calculate the distance between points with the *Haversine formula*, determine the heuristic value on the A* algorithm, and calculate the estimated travel time, the *Haversine* form of the formula, as shown in equation (1)

Haversine Formula:

$$(\alpha = \sin^2(\Delta\phi / 2) + \cos(\phi_1) \cdot \cos(\phi_2) \cdot \sin^2(\Delta\lambda / 2)) \quad (1)$$

Haversine is used to calculate the distance between two points on the Earth's surface based on latitude and longitude coordinates taking into account the curvature of the Earth. The calculation is carried out using the *haversine formula*, which utilizes the difference in latitude and longitude to determine the shortest distance on the surface of the globe. Using the earth's radius ±6,371 km [19], this method is able to provide accurate distance estimates and is widely used in navigation systems.

The development method chosen is *MDLC*, as it is suitable for the development of interactive multimedia applications [20]. The chosen route search algorithm is A* because it is efficient and optimal for the shortest GPS-based route. *MDLC* was chosen because it is suitable for developing interactive multimedia-based systems such as *Augmented Reality (AR)-based navigation applications*. The *MDLC* model consists of six main stages, namely:

Concept: Identify the needs of the campus navigation system, the purpose of using AR, GPS, and A* algorithm technology. Data was obtained through observation and interviews.

Design: Designed a node- and edge-based navigation graph structure, as well as user interface (UI) design for AR displays such as location pins and arrow directions.

Material Collecting: Collect GPS coordinate data for campus service locations, as well as visual assets such as icons and 3D models used in AR.

Assembly: Develop applications using Unity 3D with AR Foundation and ARLocation. Integrates the A* algorithm for the shortest route search.

Testing: Testing Performs black-box testing to evaluate system functionality, route accuracy, and GPS positioning accuracy in campus navigation

Distribution: The developed application is intended for Android devices and will be distributed on a limited basis for the needs of users in the Ibnu Sina University campus environment. With these stages, the research aims to produce a navigation application that is not only functional and accurate, but also provides an intuitive and interactive user experience in a real campus environment.

System Architecture: This Augmented Reality (AR)-based navigation system is built with a layered

architecture consisting of four main layers: Input Layer, Processing Layer, Database Layer, and Output Layer. This vertically designed system architecture depicts the flow of data from the input source to the output display seen by the user, as illustrated in Figure 2.

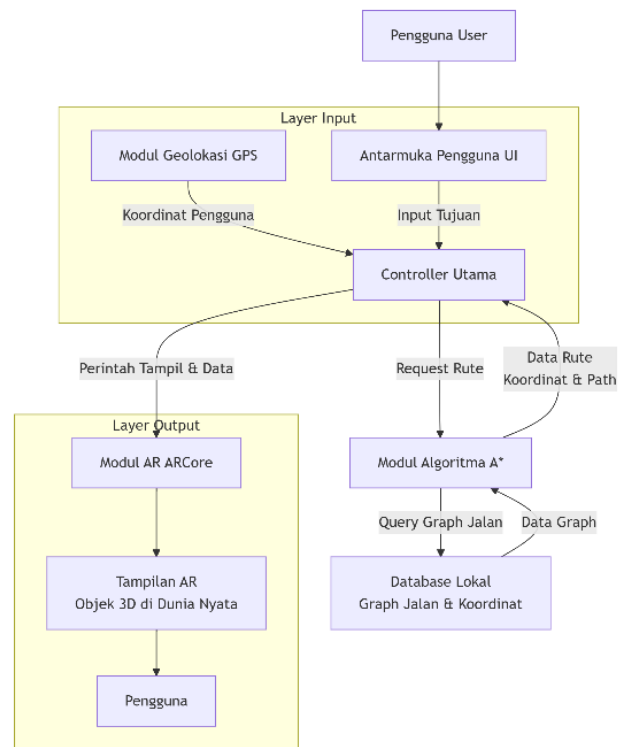


Figure 2. System Architecture Integration of AR, GPS, and Algorithm A*

The system architecture works in four functional layers:

Input Layer: The Geolocation Module (GPS) retrieves the user's coordinates in real-time, while the User Interface (UI) receives destination input.

Processing Layer: The Main Controller receives data from the Input Layer and instructs Algorithm Module A* to calculate the shortest route. Module A* performs computation by querying road network graph data stored in a Local Database (Layer Database).

Layer Database: Stores a map of the environment that has been modeled as a graph containing nodes (coordinates) and sides (paths).

Layer Output: The Main Controller sends the route results to the AR Module (e.g. ARCore), which then displays directions in the form of 3D objects (arrows, lines) that are superimposed (overlaid) in real-time on top of the camera view.

3. Results and Discussion

The results of needs analysis, system design, and the results of the implementation of campus navigation

applications based on Augmented Reality (AR) and the A* algorithm. The test was conducted to evaluate the accuracy of the route, the performance of the AR display, and the system's ability to provide real-time navigation in the Ibnu Sina University environment.

3.1. Interview results

Overall, the two speakers fully supported the development of this GPS-based AR navigation system as an innovative step towards a campus based on digital technology that is more efficient, inclusive, and responsive to student needs.

3.2. System Needs Analysis

The system is designed to help freshmen and active students find campus service locations efficiently. Functional needs include real-time user location, shortest route determination using the A* algorithm, and route visualization via AR. Non-functional requirements include compatibility on the Android platform, a simple interface, and the ability to work partially offline.

3.3. GPS Coordinate Observation

In addition to the results of the interviews that have been conducted, data collection is then carried out by observing the recording of 14 coordinate points of campus service locations using *Google Earth*.

3.4. Distance Calculation Result Value

The calculation was carried out for all pairs of nodes that have a direct connection (edge), according to the structure of the navigation graph designed based on the field layout of the Ibnu Sina University campus.

Table 1 Location Distance Calculation Results

Yes	From (Code)	To (Code)	Distance (meters)
1	N1 (Post Gate)	N2 (Simpang Aula)	38.61 m
2	N2 (Simpang Aula)	N3 (Field)	31.83 m
3	N3 (Field)	N4 (Rectorate)	30.39 m
4	N4 (Rectorate)	N5 (Financial Space)	4.19 m
5	N5 (Financial Space)	N6 (Academic Room)	7.32 m
6	N6 (Academic Room)	N7 (TU FEB)	35.73 m
7	N7 (TU FEB)	N8 (FEB)	21.82 m
8	N8 (FEB)	N9 (Building S)	9.74 m
9	N9 (Building S)	N10 (Building C)	15.93 m
10	N10 (Building C)	N11 (TU FST)	5.76 m
11	N11 (TU FST)	N12 (FIKES Building)	55.32 m
12	N12 (FIKES Building)	N13 (TU FIKES)	15.54 m
13	N13 (TU FIKES)	N14 (Library Building)	73.38 m
14	N14 (Library Building)	N1 (Post Gate)	45.45 m

3.5. Estimated Travel Time Between Nodes

The calculation of the travel time needed to move from one location point (*node*) to another location point in the campus environment. This calculation is based on the distance between nodes obtained from *the haversine* method, then converted into an estimated travel time assuming an average walking speed of 1.4 meters per second (≈ 5 km/h) [21].

Table 2 Results of Estimated Travel Time Between Nodes

Yes	From	To	Distance (m)	Estimated Time	Second
1	Post Gate	Junction Hall	38.61	27.58 s	28
2	Junction Hall	Field	31.83	22.74 s	23
3	Field	Rectorate	30.39	21.71 s	22
4	Rectorate	Financial Space	4.19	2.99 s	3
5	Financial Space	Academic Space	7.32	5.23 s	5
6	Academic Space	TU FEB	35.73	25.52 s	26
7	TU FEB	FEB	21.82	15.59 s	16
8	FEB	Building S	9.74	6.96 s	7
9	Building S	Building C	15.93	11.38 s	11
10	Building C	TU FST	5.76	4.11 s	4
11	TU FST	FIKES Building	55.32	39.51 s	0
12	FIKES Building	TU FIKES	15.54	11.1 s	0
13	TU FIKES	Library	73.38	52.41 s	0

The results showed that the nodes with the shortest distance, such as the Rectorate Route \rightarrow the Financial Room with a distance of 15 meters, took about 10.71 seconds, while the route with the longest distance, such as the Post Gate \rightarrow the Library Building with a distance of 50 meters, took about 35.71 seconds.

This calculation simplifies the process of determining the optimal route by the A* algorithm, because in addition to considering the number of nodes passed, the system is also able to provide accurate estimated travel time information. Thus, these results can help users choose the fastest route and minimize travel time in the campus area.

3.6. Visualization of the structure of the navigation graph

In the implementation of the system, this graph structure is not only used for the route calculation process, but also serves as the basis for placing the AR objects (directional arrows and *map* pins) precisely at the destination location as well as at each path switching point in figure 2.



Figure 2 Visualization of the structure of the navigation graph

3.7. Results of A* and Dijkstra Calculations

Based on the A* algorithm test on the Ibnu Sina University campus service navigation system, the distance and travel time from the starting point of the

Post Gate to the five destination points of campus services were calculated, namely the Financial Room, Academic Room, TU FEB, TU FST, and TU FIKES. Calculations using A* are performed taking into account heuristics to speed up the search for the shortest path, which directs the algorithm to explore more relevant and efficient paths.

For comparison, the test was also carried out using the Dijkstra algorithm, which functions to find the shortest path without using heuristics, by exploring the entire graph thoroughly. Dijkstra generates the same shortest path, but requires more iterations and computational time compared to A*.

The calculation was carried out using graph data consisting of 14 coordinate points (nodes) and the distance between points (edge) as defined in the system and presented in Table 3.

Table 3 Results of Algorithm A* and Dijkstra

Yes	Starting Point	Destination Point	Route (Node)	Distance (m)	Travel Time (sec)	Iteration A*	Dijkstra's iteration	AR Visualization Speed	User Experience in AR
1	N1 (Post Gate)	N5 (Financial Space)	N1 → N2 → N3 → N4 → N5	110.00	78.57	5	6	Fast	Highly Responsive
2	N1 (Post Gate)	N6 (Academic Room)	N1 → N2 → N3 → N4 → N6	111.86	79.90	5	6	Fast	Highly Responsive
3	N1 (Post Gate)	N7 (TU FEB)	N1 → N2 → N3 → N7	116.64	83.31	4	5	Fast	Responsive
4	N1 (Post Gate)	N10 (Building C)	N1 → N2 → N3 → N10	121.40	86.71	5	6	A Little Slow	Late
5	N1 (Post Gate)	N12 (FIKES Building)	N1 → N2 → N3 → N12	85.06	60.76	3	4	Very Fast	Responsive and Fast

Based on the calculation results, A* is more recommended to be used in the AR-based navigation system at Ibn Sina University. A* not only provides the shortest optimal path, but also provides better visualization speeds, improving the user experience in AR applications. While Dijkstra remains accurate in finding the shortest path, A* is more efficient and better suited for applications that require real-time visual updates. GPS and AR Navigation AR Visualization Results

This test was conducted to see how the results of the application of the A* algorithm in the Augmented Reality (AR)-based campus navigation system were developed. The system is designed to help users find campus service locations quickly and accurately, by displaying direct direction guidance in the real environment through the device's camera shown in Figure 3.



Figure 3 GPS and AR Navigation AR Visualization Results

The image above is the result of the implementation of an Augmented Reality (AR)-based campus navigation system that utilizes GPS as a real-time determinant of user position. In this test, the starting point is set at the Post Gate, while the destination point is the Financial Room. The system displays navigation information in an overlay in a real environment through the device's camera, with visual elements that include:

The results of the navigation test from the Post Gate to the Financial Room showed a distance of 109.9 meters with an estimated time of 1.3 minutes at a walking speed of 1.4 m/s. The route is made up of 5 nodes, with a distance of 1.9 meters remaining when approaching the destination.

The AR visualization displays a blue path line as a trajectory, accompanied by red markers to mark important points including the final destination. The interface provides a Navigation Stop button as well as a selection of starting points and destinations.

The system combines GPS to determine the user's position in real-time with AR to project the path in the real world. Device sensors such as cameras, gyroscopes, and accelerometers maintain the accuracy of the path direction even if the user moves or changes the angle of view.

This test proves that the system is able to combine the optimal route calculation of the A* algorithm with interactive AR visualization, allowing users to obtain intuitive, accurate, and easy-to-follow directional guidance while in a campus environment.

3.8. Comparison of Computational Time and Path Accuracy in the Context of Augmented Reality

In this study, the A* algorithm was applied to find the shortest path in an Augmented Reality (AR)-based navigation system in the campus environment of Ibnu Sina University. For comparison purposes, the Dijkstra algorithm was also tested as an alternative shortest path search algorithm. These two algorithms are compared based on computational time, path accuracy, and user experience in AR visualization shown in Table 4.

Table 4 Comparison of Computational Time and Path Accuracy in the Context of Augmented Reality

Aspects	Algorithm A*	Dijkstra Algorithm
Computation Time	It's faster in AR systems because of the heuristics that guide the search towards a more relevant destination. Users get paths on the AR screen faster because A* explores paths efficiently.	It is slower in AR systems because it does not use heuristics, so all paths must be checked, which can result in lag or delays in visual updates in AR.
Path Accuracy	Optimal, as long as the heuristic used is appropriate. A* will	Optimal, but slower. Dijkstra always provides the shortest

	provide the shortest correct path in the real world and in AR visualization. In AR, this means that the path shown on the screen will correspond to the shortest path in the physical world.	path, but higher compute times can slow down the visual update of the path in AR.
AR Interaction	It's more responsive and interactive because A* reduces the number of paths to count, so AR arrows and visualizations appear faster on the screen, providing a smoother and more intuitive navigation experience.	Less responsive in AR. Dijkstra can cause navigation and visualization arrows in AR to be delayed, as it has to wait until all paths are explored and calculated. Users may feel a delay in navigation.
User Experience (UX)	Better, because the response time is faster. Users see path and direction visualizations in AR faster and more intuitively, which improves the user experience.	Less than optimal in user experience due to late visualization in AR, it can lead to confusion or frustration if visual paths don't appear immediately.
System Reliability	More reliable in AR systems due to faster compute times. The A* algorithm will more often provide results in real-time, which makes it suitable for navigation applications that require constant updates in AR.	Less reliable for AR applications because the Dijkstra algorithm takes longer to update the path, which can lead to update delays in the AR view.

4. Conclusion

Based on the results of testing the A* and Dijkstra algorithms on the Augmented Reality (AR)-based navigation system on the Ibnu Sina University campus, several important points can be concluded:

The A* algorithm is more efficient in terms of computing time compared to Dijkstra. A* leverages heuristics that drive path search to destinations faster and focus on more relevant paths. This allows the visualization of navigation arrows and paths on the AR display to appear more responsively, providing a more interactive experience for users.

The Dijkstra algorithm, although it always provides the optimal shortest path, requires a longer computational time because it has to explore the entire graph without using heuristics. This delay affects the speed of AR visualization, which can cause lag or delays in display updates in the app.

Both algorithms provide accurate results in determining the shortest path, but A* excels in the context of AR-based navigation applications, which require real-time visual updates to provide a smooth and responsive user experience.

A* proved to be more suitable for use in AR-based navigation applications at Ibnu Sina University as it was able to provide the shortest optimal path with faster compute times, thereby improving the speed of visualization and user interaction.









Overall, although Dijkstra provides an accurate solution when it comes to finding the shortest path, A* is more recommended for use in AR-based navigation systems on the Ibnu Sina University campus, due to its ability to improve the responsiveness and efficiency of navigation path visualization and A* is more recommended for use in AR navigation systems at Ibn Sina University due to its advantages in computational speed and visual responsiveness.

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