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PAPERS

Integrating GPS and WiFi signal strength analysis for enhanced building entrance localization using fuzzy logic

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This paper presents a method for improving the accuracy of determining a person's proximity to a building entrance in urban and indoor settings, where the Global Positioning System (GPS) and Wireless Fidelity (WiFi) signals are often interfered with. Fuzzy logic can be applied to variations in signal strengths in order to interpret the inverse relationship between GPS signals weakening and WiFi signals strengthening as a person approaches or enters a building. As a result, a fuzzy set for GPS signal strengths between 14 and 33 dBm and WiFi signal strengths between –68 and –31 dBm is created, separating them into weak, medium, and strong signals. By using fuzzy rules, the system can accurately determine if a user is 'far,' 'near,' or 'at' an entrance, mimicking real-life transitions from outdoor to indoor environments. The accuracy of this approach exceeded 90% based on real-world data, and it significantly improved user experience in navigation applications, particularly in cases where GPS does not work well.

Keywords: fuzzy logic, GPS signal processing, WiFi signal analysis, urban navigation, indoor localization, building entrance detection

1 Introduction

Urban and indoor navigation landscapes are being altered at a rapid pace, and determining where a person is has recently become more of a challenge than ever. Such an issue frequently arises in the case of a building entrance [1]. The Global Positioning System is a revolutionary technology that offers superior outdoor precision, but its ability to accurately determine position within a city or a building is compromised by signal scattering [2]. However, GPS signals are unreliable indoors because it is unavailable or very restricted which makes them ineffective. Indoor localization techniques often use landmarks to detect the accurate location of users and track them. These landmarks are stairs, WiFi access points, elevators, and others. Building entrances act as precise landmarks for precisely tracking users or locating objects, especially for those who are just entering buildings [3]. Fuzzy logic is an approach that does not rely on binary true-or-false logic systems, instead, its computing is based on a degree of true [4]. Based on fuzzy logic, nuanced, often ambiguous scenarios in real life are reflected in different degrees of truth. In urban navigation, signal strength variations are characterized by gradations and uncertainties, making it exceptionally suitable for interpreting these variations. By constructing an array of fuzzy sets and rules calibrated to the specific signal ranges encountered in urban contexts, we can mirror the cognitive processes humans use to realize proximity from these fluctuating signals. Indoor localization techniques often require information, such as the building's blueprint, to detect precise locations. A key challenge arises when a user transitions from an outdoor environment, where GPS is used for localization, to an indoor environment where GPS signals are weak or unavailable. In this scenario, the localization system must switch from GPS localization to the indoor localization method. This transition shows the importance of accurately detecting a building's entrance.

This paper shows the effectiveness of fuzzy logic in addressing the issue of detecting building entrances to seamlessly switch from relying on GPS to an indoor localization method when a user enters a building. By analyzing the signal strengths of GPS and WiFi, the proposed approach categorizes GPS and WiFi signals into fuzzy sets ('weak', 'medium', 'strong') and integrates these into a set of fuzzy rules. The main idea of this paper is to detect the entrances based on the behavior of GPS and WiFi signals at the vicinity of the entrance.

The main contributions of this paper are:

1. Study the behavior of the WiFi and GPS signals at the buildings entrance.
2. Design fuzzy logic roles to represent the correlation between WiFi and GPS signals.
3. Testing the system in real environment.

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2 Related work

Indoor localization has gained popularity in research community as it serves a purpose of a targeting device to exact locations inside the buildings. As Wi-Fi becomes a widespread technology used inside various buildings, the majority of the time indoor localization depends on the strength of Wi-Fi signals to measure the distance. The society has reached a level whereby the majority of devices have embedded sensors fit into each device, making the smart technologies available to many. Alternatively, nowadays the main role of these sensors is to locate users inside buildings, where the satellites are not always available. Lots of indoor localization services are available now to transform any tranquil and peaceful environment into something very dynamic and busy. The Inertial Navigation System (INS) utilizes Inertial Measurement Units (IMUs), such as accelerometers and gyroscopes, to determine the location and directional movement of objects [5]. Fingerprinting methods utilizing wireless technologies like Wi-Fi and Bluetooth are among the most popular approaches for indoor localization [6]. Other techniques include Time of Arrival (TOA), trilateration, and Angle of Arrival (AOA), which rely on signals from at least three different sources to determine positions accurately [7]. These methods are essential for enhancing the accuracy and reliability of indoor positioning systems.

With fuzzy logic, problems with unclear or inaccurate information can be solved with incredible precision. To make new conclusions from known facts, fuzzy logic relies on fuzzy if-then rules. Unlike traditional binary logic, this approach allows for more nuanced decision-making when data may not always be clear-cut, making it ideal for real-world problems where no clear-cut answer exists [8]. Reimeringer et al., proposed a fuzzy logic framework for an adaptive visual and voice advertisement system that can better target the needs of different EU cultures [9]. Adapting this system to specific cultures requires comprehensive localization, as it must take into account cultural differences among ads. It is evident that the use of fuzzy logic is becoming more prevalent in the process of localization [9-11]. The building entrance is the ideal starting point for most indoor localization methods because it serves as an initial starting point for tracking. A machine learning approach is used to detect the location of building entrances based on some features [12]. Fuzzy logic has been widely used in enhancing systems in buildings. Research focused on reducing the amount of elevator movement is proposed in [13]. An approach for detecting the optimal positions for installing WiFi access points is presented in [14].

These days, building safety and security are essential. For instance, in the event of a fire, people must be evacuated beforehand to save lives. In these situations, AI and IoT are crucial because they can aid in figuring out the best course of action when an emergency arises [15-17]. The most crucial element in these situations is the accurate identification of the entrance location; during the evacuation, the appropriate path must lead to the entrance.

Based on the reviewed literature, the proposed method diverges from existing techniques in several key aspects: Firstly, to our knowledge, it is the inaugural approach that employs fuzzy logic to identify building entrances by correlating WiFi RSS with GPS signals. Secondly, it is among the few approaches that prioritize the detection of building entrances as a primary concern.

3 Proposed approach

In the quest to enhance navigational aids and location-based services, particularly within the intricate tapestry of urban environments and indoor settings, the limitations of conventional positioning technologies such as Global Positioning System (GPS) and WiFi have come to the forefront. The motivation behind this research stems from a critical observation: GPS, while ubiquitous in outdoor navigation, faces significant challenges in accurately determining positions in densely built areas or indoors due to various uncontrollable factors. Similarly, indoor WiFi is intrinsically less useful for positioning outside or in places where access is restricted. This contradiction creates a special challenge in creating a universal solution that can smoothly switch between outdoor and indoor settings, guaranteeing reliable and accurate location detection.

There are a number of factors beyond the control of any governing body that significantly affect GPS technology, which has become the backbone of contemporary navigation systems. These include atmospheric conditions that can distort signal paths, physical obstructions that block the line of sight of satellites, such as buildings or natural landscapes, and the quality of the receiver device. The presence of these variables introduces uncertainties to GPS-based location estimations, making the technology less reliable in urban canyons or indoor settings with poor satellite visibility. Conversely, WiFi-based positioning systems offer a viable alternative for indoor environments, capitalizing on the proliferation of WiFi networks. However, their utility is inherently limited to areas within the signal range, and they are virtually inapplicable for outdoor navigation. Moreover, access to WiFi networks may be restricted, further constraining their usability for public navigation solutions. These observations highlight a significant gap in the current landscape of navigation technologies: the lack of a versatile system capable of providing accurate positioning information across diverse environments. Traditional methods, reliant on either GPS or WiFi, fall short in addressing the full spectrum of navigational needs, particularly at the critical junctures of outdoor to indoor transitions.

The proposed approach seeks to address the inherent challenges of urban and indoor navigation by leveraging the nuanced dynamics of GPS and WiFi signals, interpreted through the lens of fuzzy logic. This approach aims to enhance the precision of locating building entrances. Herein, we detail the methodology that underpins this innovative navigation system. During the development of the proposed method, the GPS and WiFi signal strength is analyzed in detail. GPS signals typically decrease in strength as users move from open outdoor environments to buildings, while WiFi signals, which are stronger indoors, strengthen in similar situations. The proposed approach defines GPS and WiFi ranging from 14 to 33 dBm and –68 to –31 dBm, respectively. To handle imprecision effectively, fuzzy logic is applied to categorize signal strengths into fuzzy sets ('weak', 'medium', 'strong') and map each via membership functions. A set of comprehensive rules and a fuzzy inference system are used to output user proximity categories ('far', 'near', 'at entrance') based on the combination of signal strengths to infer proximity to building entrances. The final step of the methodology, defuzzification, converts the fuzzy output back into crisp values, employing the centroid method to estimate the user's distance.

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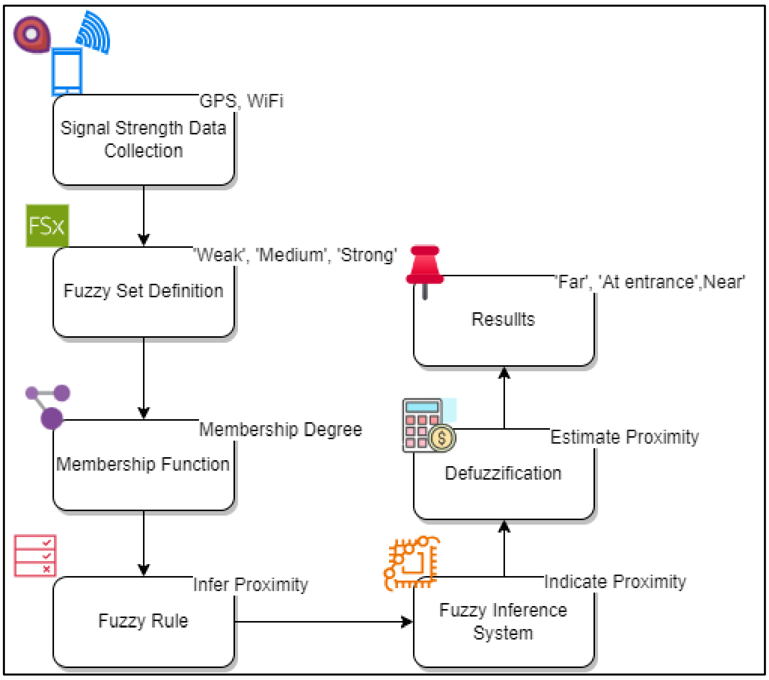

Fig. 1. System design

3.1 System design

Figure 1 illustrates the proposed fuzzy logic-based navigation system which is designed to accurately determine a user's proximity to a building entrance by analyzing GPS and WiFi signal strengths. It consists of the following components.

3.1.1 Signal strength data collection

This component is responsible for gathering raw signal strength data from the user's device. GPS signal strength is measured to determine the user’s outdoor location accuracy, while WiFi signal strength helps infer indoor proximity. The data collected at this stage serves as the input for the fuzzy logic system.

3.1.2 Fuzzy set definition

In this phase, signal strengths are categorized into fuzzy sets based on their values. For GPS and WiFi signals, sets such as 'weak', 'medium', and 'strong' are defined. This categorization allows the system to process signal strengths in a manner that mimics human reasoning, accommodating the inherent uncertainty and variability in signal strength measurements.

3.1.3 Membership function application

Membership functions assign a degree of member-ship to each signal strength value within the fuzzy sets defined earlier. These functions quantify how strongly a particular signal strength belongs to a set, allowing for partial membership across different sets. This process transforms crisp signal strength data into fuzzy values that can be manipulated by the system. This approach allows for smooth transitions between categories, reflecting the often-gradual change in signal strength as users move through different environments.

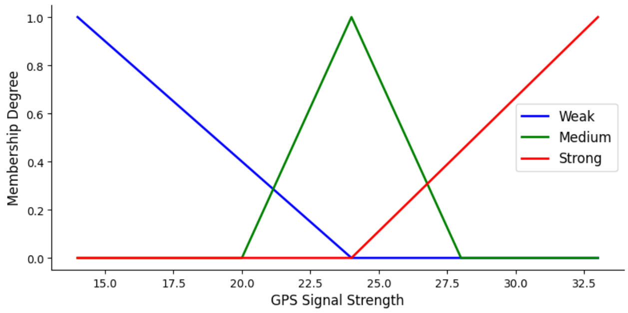

Fig. 2. GPS membership function

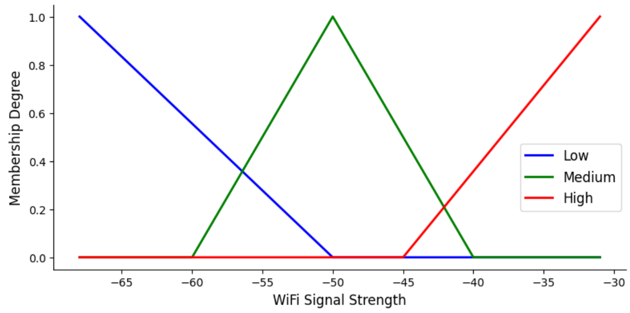

Fig. 3. WiFi membership function

Figure 2 shows the GPS membership function which categorizes GPS signal strength into three fuzzy sets: 'Weak', 'Medium', and 'Strong'. These sets help the system interpret varying levels of GPS signal strength, which is crucial for outdoor navigation and transition areas such as entrances to buildings. The universe of discourse for the GPS signal strength is defined from 14 to 33 dBm, representing the possible range of signal strengths measured.

- Weak GPS signal (14 to 24 dBm): This range is characterized by the lowest signal strengths, typically experienced in challenging environments where direct line-of-sight to GPS satellites is obstructed, such as urban canyons or indoor settings. A signal strength that falls into this category suggests that the user is either indoors or in an area where GPS reliability is compromised.
- Medium GPS signal (20 to 28 dBm): Represents an intermediate level of signal strength, indicating that the user may be transitioning between outdoor and indoor environments, or in open areas surrounded by partial obstructions. This range captures the variability of signal strength in semi-enclosed spaces or near entrances.
- Strong GPS signal (24 to 33 dBm): The highest signal strengths, typically observed in open, unobstructed outdoor environments. 'Strong' classification indicates optimal conditions for GPS-based navigation, with clear visibility to the sky and minimal interference.

The membership functions for these sets are triangular, providing a straightforward method for mapping signal strengths to degrees of membership.

Figure 3 shows the WiFi membership function classifying WiFi signal strength into three fuzzy sets: 'Low', 'Medium', and 'High'. Given the inverse nature of WiFi signal strength values (where a more negative number represents a weaker signal), the universe of discourse is set from –68 dBm to –31 dBm, encompassing the typical range of indoor WiFi signal strengths.

- Low WiFi signal (–68 to –55 dBm): This range indicates weak WiFi signal strength, commonly found in areas far from WiFi access points or in environments with substantial physical barriers that attenuate the signal. A 'Low' classification might suggest that the user is either outside the effective range of indoor WiFi networks or in a location within a building that is shielded or distant from access points.
- Medium WiFi Signal (–60 to –40 dBm): Represents moderate WiFi signal strength, likely encountered when the user is within a building but not in immediate proximity to a WiFi access point. This range is indicative of a user being indoors, with the signal strength affected by distance to access points, walls, and other obstructions.
- High WiFi Signal (–45 to –31 dBm): The strongest WiFi signals, usually observed when the user is near or in direct line-of-sight to an access point. A 'High' classification strongly suggests indoor presence, potentially near the building entrance or an area with dense WiFi coverage.

Similar to the GPS membership functions, the WiFi signal strength categories also use triangle membership functions. It can allow them to all partial memberships ranges between the categories. As indoor locations have ranges, these given functions are beneficial when it comes to partial memberships. As a result of the used membership function, the system performs the built handler. This developed handler can address and control the uncertainties and overlaps between the GPS and WiFi signal strengths. Thus, the system can accurately estimate the entrance and improve navigation in both indoor and outdoor situations.

3.1.4 Fuzzy rule application

A fuzzy logic system is proposed to determine the proximity of a user to a building entrance by using a series of rules. They describe how GPS and WiFi signal strengths relate to the output fuzzy set (proximity to the entrance) using logical statements. A rule may state, for example, that if the GPS signal is 'weak' and the WiFi signal is 'strong', then the entrance is 'near'.

3.1.5 Fuzzy inference system

To derive an output, the fuzzy inference system applies rules to the input fuzzy values. By combining all the applicable rules, it generates a fuzzy output value that represents the user's estimated proximity to the entrance. Based on all the input data, this system aggregates and evaluates the rules using fuzzy logic operations.

3.1.6 Defuzzification

In this component, the fuzzy output value from the inference system is converted into a crisp, quantitative value that represents the user's proximity to the entrance. A defuzzification method, such as the centroid calculation, is used to deduce the inferred proximity from a single number, enabling the output to be interpreted and utilized.

3.1.7 Proximity estimation

In the final step of the system, the defuzzified value is interpreted as the user's estimated proximity to the building entrance. The estimated location can be used to trigger notifications, guide navigation, or integrate with other applications that need precise location data. Through fuzzy logic analysis of GPS and WiFi signal strengths, proximity estimation provides actionable insight.

4 Evaluation and results

The primary objective of our evaluation was to assess the accuracy and reliability of our proposed fuzzy logic-based system for detecting a user's proximity to building entrances, using variations in GPS and WiFi signal strengths. We aimed to validate the system's performance in real-world scenarios, highlighting its potential to enhance urban and indoor navigation.

4.1 Experimental environment

Figure 4 illustrates the experimental setup, featuring multiple WiFi access points, one of which is positioned near the main entrance of the building. The user starts outside and walks toward the entrance until entering the building. Throughout this movement, WiFi RSS values and GPS signals are recorded to gather data.

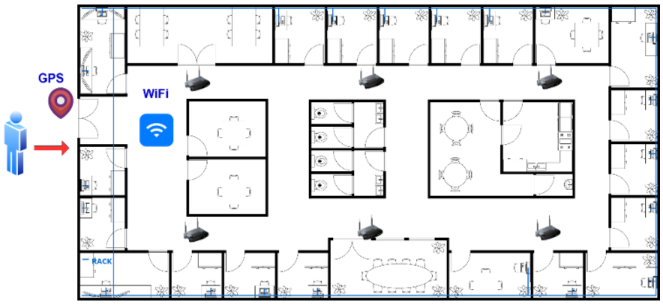

Fig. 4. Experimental environment

4.2 Experimental results

In this section, we present the results of the components of the proposed approach, such as the evaluation of GPS and WiFi signals and the overall results of the fuzzy system.

4.2.1 GPS evaluation

Figure 5 demonstrates the degradation of the GPS signal as the user approaches the entrance of the building. The figure reveals that the GPS signal persists within the building, particularly near the entrance. Note that the building's position is marked at distance (0), indicating that negative distances represent positions inside the building.

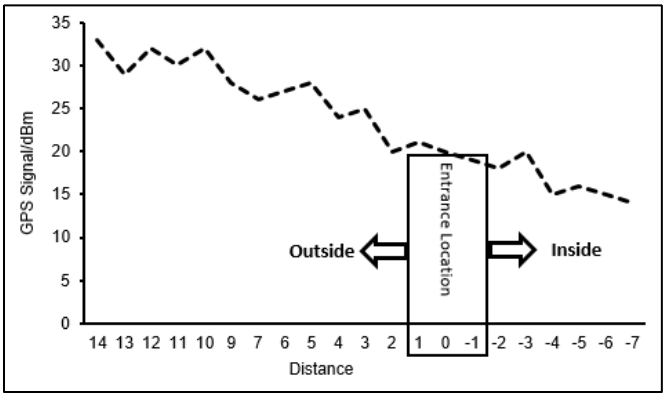

Fig. 5. GPS results

4.2.2 WiFi evaluation

Figure 6 shows that WiFi RSS values increase as the user approaches the building entrance, peaking when the user is indoors due to the signal being in line of sight with the user.

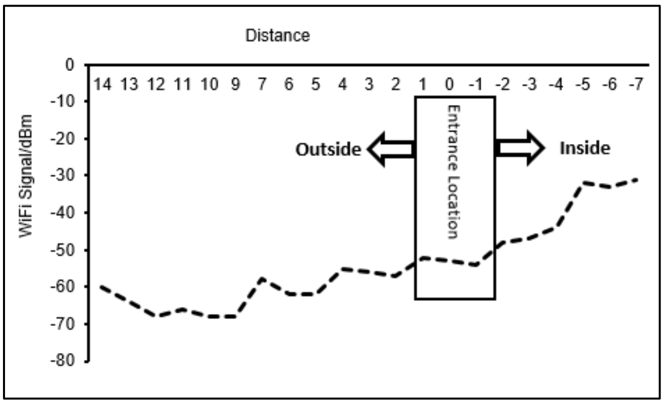

Fig. 6. WiFi results

It is evident from Figs. 5 and 6 that GPS signals decrease as one approaches the building entrance, whereas WiFi RSS signals increase. Given the overlap of signals at the entrance, fuzzy logic appears to be the best option for precisely determining the entrance's location.

4.2.3 Fuzzy logic results

The fuzzy logic-based navigation system demonstrated a high degree of accuracy across the tested environment as shown in Fig. 7. Specifically, the system achieved an overall accuracy of approximately 91%, underscoring its effectiveness in interpreting the nuanced changes in GPS and WiFi signal strengths to determine proximity to building entrances. The breakdown of accuracy by proximity category was as follows:

- Far: 85% accuracy, indicating strong performance in identifying when users were at a considerable distance from an entrance.
- Near: 81% accuracy, showcasing the system's capability to detect users approaching or in the vicinity of entrances.
- At entrance: 99% accuracy, reflecting the system's precision in identifying users at or very close to entrances.

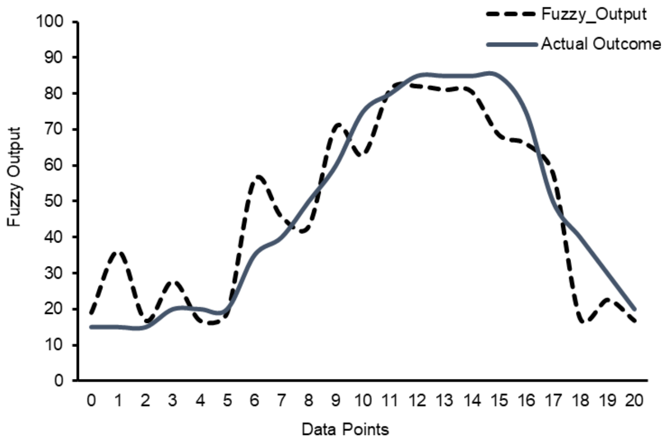

Fig. 7. Fuzzy system output

4.2.4 Analysis of results

The primary observations of the system are presented by the results displayed in Figs. 5 and 6. Figure 4 illustrates the presence of multiple WiFi access points in the area, indicating a strong indoor WiFi signal that can be used as a signal to enter the building. Figure 5 illustrates how strong the WiFi signal is when a user enters the building; for example, it can reach –30 dBm when a user is five meters inside the building. Thus, the WiFi signals provide compelling proof of whether the user is inside or not.

5 Discussion

The high accuracy rates across different proximity categories affirm the robustness of the fuzzy logic-based approach. Notably, the system's performance in dense urban areas and indoor settings marks a significant improvement over traditional GPS-based navigation systems, which often struggle in these environments. The slight variation in accuracy between categories can be attributed to the inherent challenges in precisely defining signal strength thresholds for 'near' and 'at entrance' scenarios, where signal fluctuations are more pronounced.

The obtained results show that the system is flexible and also attribute adaptability to the strengths of the system. Indeed, the fuzzy logic framework makes it possible to change the membership functions and rules relatively easily to resemble the environment better if it has some more individual characteristics or to refine the existing ones by adding even more data. The high accuracy and adaptability make the system a highly promising tool for urban and indoor navigation. One of the limitations of the system is that there must be WiFi access points close to the entrance to run the system. The fuzzy system rules depend on the presence of WiFi access points near the building.

6 Conclusion

The proposed fuzzy logic-based approach achieved high accuracy rates across different proximity categories, and significantly improved performance in dense urban areas and indoor environments compared to traditional GPS-based navigation systems. The results strongly support the viability of using a fuzzy logic-based system for enhancing the accuracy of building entrance detection in navigation applications. By effectively leveraging the interaction between GPS and WiFi signal strengths, the approach presents a context-aware approach to urban and indoor navigation challenges. One of the limitations of the system is determining the best range of GPS and WiFi signals range. In future work, dynamic range detections of the signals will be determined. Furthermore, optimizing the system, investigating its amalgamation with additional location-based innovations, and broadening its suitability for diverse navigational tools will be considered.

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