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FUZZY LOGIC-BASED ARRIVAL TIME ESTIMATION FOR INDOOR NAVIGATION USING AUGMENTED REALITY

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ABSTRACT: In recent years, Augmented Reality (AR) has gained popularity in various industries due to its ability to enhance efficiency, provide real-time information and data, and maintain user awareness of their surroundings. One of the applications of AR is in navigation, but most existing systems primarily focus on outdoor environments, neglecting indoor spaces. Mobile applications designed for indoor navigation often rely on expensive and computationally demanding beacons or natural markers to track the user's location along a predetermined path. Furthermore, traditional navigation estimation methods based on GPS are ineffective for indoor navigation. This study proposes a mobile AR application for indoor navigation that uses an intelligent signage algorithm based on fuzzy logic to estimate arrival time. The algorithm takes phone acceleration in the x and z directions as inputs and employs triangular-shaped membership functions for input and output variables. The experimental results indicate the feasibility of using fuzzy logic to estimate arrival time for indoor navigation, with an average prediction error of 5.82%.

ABSTRAK: Beberapa tahun ini, Realiti Terimbuh (AR) telah menjadi popular dalam pelbagai industri kerana keupayaannya meningkatkan kecekapan, menyediakan maklumat dan data secara masa nyata, dan mengekalkan kesedaran pengguna terhadap persekitaran sekeliling. Salah satu aplikasi AR adalah dalam navigasi, tetapi kebanyakan sistem sedia ada lebih menumpukan kepada persekitaran luar, mengabaikan ruang dalaman. Aplikasi mudah alih yang direka untuk navigasi dalaman sering bergantung pada bekon mahal dan memerlukan komputasi tinggi atau penanda semula jadi bagi menjejaki lokasi pengguna sepanjang laluan yang ditetapkan. Selain itu, kaedah anggaran navigasi tradisional berdasarkan GPS tidak berkesan bagi navigasi dalaman. Kajian ini mencadangkan aplikasi AR mudah alih bagi navigasi dalaman yang menggunakan algoritma papan tanda pintar berdasarkan logik kabur bagi menganggarkan masa ketibaan. Algoritma ini mengambil pecutan telefon dalam arah x dan z sebagai input dan menggunakan fungsi keahlian berbentuk segi tiga bagi pemboleh ubah masuk dan keluar. Dapatan eksperimen menunjukkan kebolehan menggunakan logik kabur bagi menganggarkan masa ketibaan bagi navigasi dalaman, dengan kesilapan anggaran purata sebanyak 5.82%.

KEYWORDS: *Indoor Navigation, Path Planning, Estimated Time Arrival, Fuzzy Logic.*

1. INTRODUCTION

The purpose of a navigation system is to provide users with the necessary and relevant information to guide them to their desired destination while also tracking their location on pre-established maps. According to data from the Fire and Rescue Department of Malaysia, the Department of Statistics Malaysia has released statistics on fire incidents in Malaysia. The

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statistics revealed a significant increase in the number of deaths and injuries due to indoor fire outbreaks [1].

Various factors can contribute to a high number of deaths during a fire outbreak, such as inadequate signage, complex building layouts, and panicked crowds that can lead to stampedes. The high density of people in these situations often results in a significant number of injuries and fatalities due to difficulty in movement. This highlights the significance of a navigation system that can assist individuals by providing a safer route to their desired destination. In light of this, this research aims to propose a project that can help achieve this objective by identifying the most efficient route and estimating the arrival time at the targeted location. This will provide users with added reassurance, as they will better understand how long it will take them to reach their destination.

One of the most perilous aspects of evacuation is the potential for individuals to lose their bearings [2-3]. This is particularly true for those who are unfamiliar with the layout of a building, leading to prolonged escape times. Including a legend or map of the structure can aid in their navigation. However, during severe emergencies, such as earthquakes, fires, or smoke, natural disasters can obscure signs and paths, hindering and confounding evacuation directions.

Normally, the majority of the physical signage within indoor spaces has become worn and is not kept up to date, which can cause confusion among visitors and building occupants when trying to navigate the area. This is particularly the case when there is a need to quickly evacuate a building with a complex layout [4]. Therefore, there is a need to implement augmented reality indoor navigation in order to reduce the reliance on physical signage.

Several mobile applications have been created to assist individuals in navigating through buildings. Most of the indoor augmented reality navigation systems currently available utilize either beacons or natural markers to obtain and update the user's location along a predefined path. However, implementing this method often requires the installation of expensive beacon devices and can also be computationally demanding when using natural markers. Therefore, it would be beneficial to have an alternative that is more cost-effective and less taxing on mobile devices [5-9].

There are several methods for estimating arrival time for navigation purposes. However, many rely on GPS to determine the user's location, rendering them ineffective for indoor navigation [10]. Currently, limited research is being conducted on methods for estimating arrival time for indoor navigation. As a result, it is crucial to develop new methods for estimating arrival time for indoor navigation [11].

The main aim of this study is to create an augmented reality application that assists users in navigating indoor spaces. To achieve this, we introduced a Smart Augmented Reality application with embedded intelligent signage for the Kulliyyah of Engineering (KOE) indoor spaces. A significant focus of our work is on modeling an intelligent system to estimate the time required to reach the desired destination, with a particular emphasis on analyzing the prediction errors between the estimated and actual arrival times.

2. METHODOLOGY

In this research, we employ artificial markers in place of natural markers, as the latter necessitates a significant number of computational resources, which can lead to overheating of the device. To effectively integrate artificial markers into the environment, several factors must be considered. The marker should possess a unique image with a predefined visual pattern and dimensions, be easily identifiable based on its color or shape, and be of an appropriate size.

Additionally, the marker should be visible in emergency situations. For the purpose of experimentation, we utilized QR codes as markers [12 - 13].

A single location will be selected to obtain test results for the simulation. The first floor of the E1 Kulliyyah of Engineering (KOE) building, International Islamic University Malaysia, has been chosen as it possesses an appropriate layout with appropriate movement flow and an adequate number of exit paths. The path from the Dean's Office to the Mechatronics Laboratory will be utilized for the simulation. Initially, the floor plan was obtained from the Technical Department of the Kulliyyah of Engineering. Next, the 3D floor plan was constructed using the Blender software, with the images of the floor plan serving as its foundation. It was then imported into Unity 3D in accordance with the real-world scale in meters, using the scale provided in the floor plan.

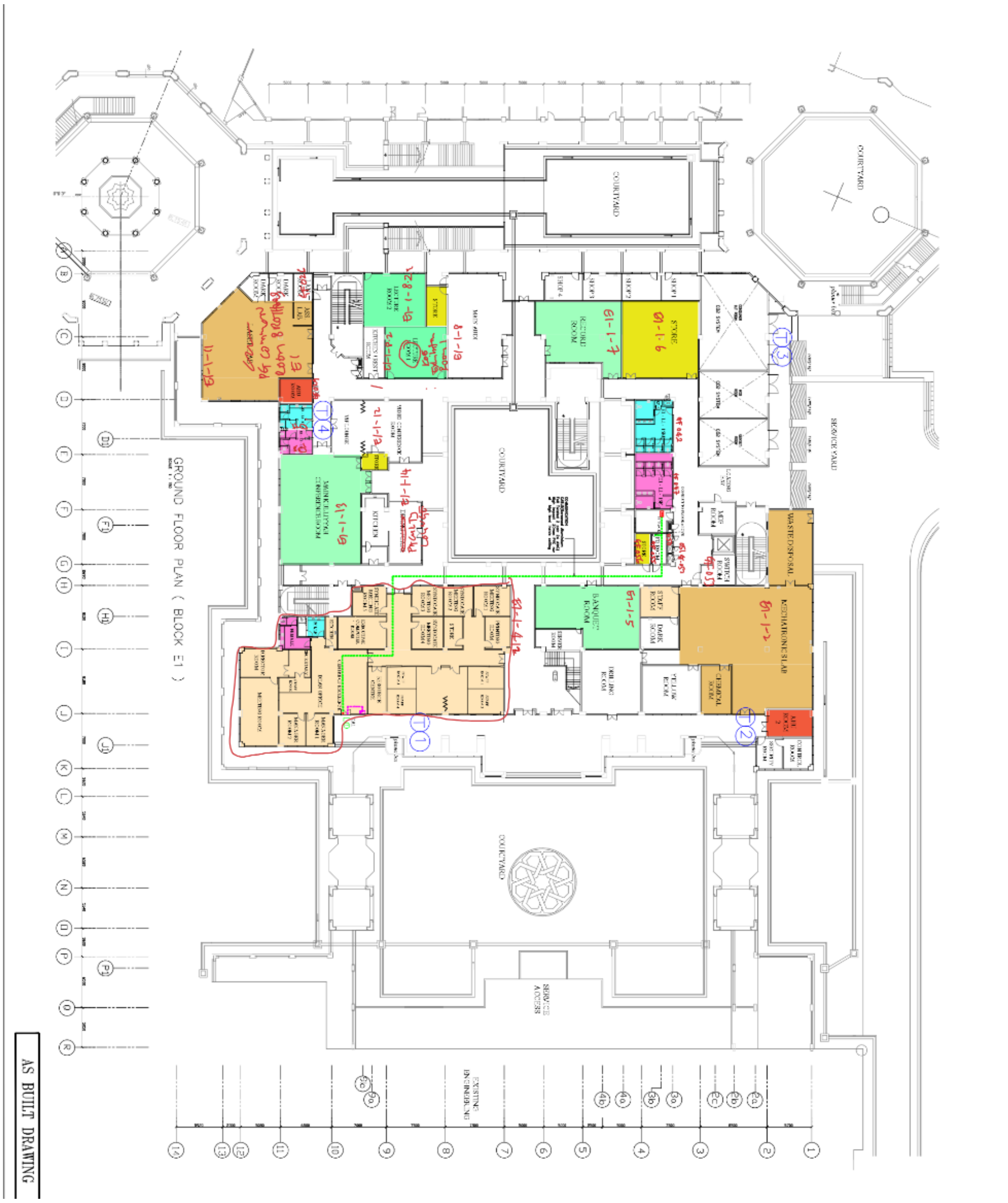

Figure 1. The original floor plan of E1 building level 1 KOE.

Subsequently, objects must be created to represent the user and the target location in the environment. In this project, a blue sphere will be utilized to represent the user, and a green cube will be employed as the target location. Additionally, it is essential to create an empty game object to indicate the QR code in the environment. These objects must be positioned at the precise location on the map, where the blue sphere is located in front of the Dean's Office as the starting point, and the green cube is located in front of the Mechatronics Laboratory as the target destination.

For the QR code, it is not necessary to incorporate it into the Unity environment. However, the name of the empty game objects that represent the QR code must correspond to the name assigned to the physical QR code in order for it to match when decoding the QR code. It is also essential to ensure that the z-axis of the empty game object for the QR code always aligns with the phone's negative z-axis, as that is the direction the camera is facing.

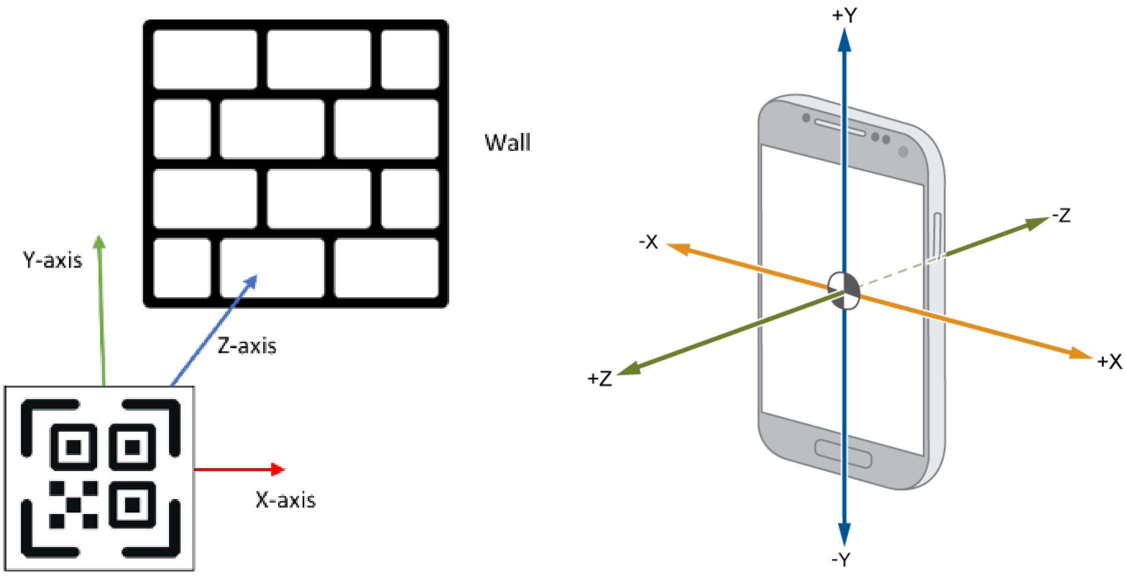

Figure 2. (a) Axis of QR code in Unity (b) Axis of mobile phone.

Unity 3D's Navigation Mesh is an inherent feature that aids developers in generating a pathfinding system within a complex environment for the simulation program. Also known as Navmesh, the Navigation Mesh facilitates the automatic programming of the agent to avoid collisions with surrounding objects. Navmesh is a two-dimensional polygon mesh that defines the area in which the selected agent can traverse. The agent is unable to walk or pass through the simulation outside of the Navmesh area.

The "bake" function will automatically generate a walkable surface for the agent, but the layer must be configured beforehand to distinguish which objects in the environment will be the surface and which will be obstacles. The bake function will result in a blue polygon that covers the surfaces that represent the walkable area. The Artificial Intelligence embedded within NavMesh will automatically compute the path to the target location utilizing the current position coordinates and target location coordinates.

In this research, we utilized an Artificial Intelligence algorithm [14] fuzzy logic to estimate the time of arrival (ETA) by utilizing acceleration as the input. Initially, we designed the membership function for the inputs and outputs. To design the membership function, it is necessary to determine the range of each membership, which can be achieved through experimentation. All experiments and simulations are conducted using a Xiaomi Mi 9T Pro Android phone, the specifications of which are detailed in Table 1.

Table 1. Xiaomi MI 9T Pro specification

CPU	RAM	OS	Battery
Qualcomm Snapdragon 855	8GB	Android 11, MIUI 12.5	4000mAh, Li-Po

Based on the data, the fuzzy logic algorithm is designed to start by determining the universe of discourse and the range of each fuzzy set. Then, the Mamdani base fuzzy rule is constructed by observing the behavior of both accelerations with time. Mamdani fuzzy logic is suitable for complex problems requiring transparency and interpretability in decision-making, particularly when linguistic rules play a crucial role, and the relationships between inputs and outputs are not easily expressed mathematically or are subject to interpretation, distinguishing it from Takagi-Sugeno-Kang (TSK) and Adaptive Neuro-Fuzzy Inference System (ANFIS). Then, by referring to the fuzzy rules and membership function, we estimated the time of arrival after the fuzzification and defuzzification process.

The accuracy of fuzzy logic is determined by running field tests with five repetitions to get the average error by comparing estimated time with actual time using the same pathway. The next sections will go over the mathematical model of fuzzy logic, its theory and approach to navigation problems, and the experimental setup used in this project.

2.1. Mathematical Equations and Theory

In reference to the collected data, we will have the following membership function where the acceleration in the x and z directions are the inputs, while the estimated time of arrival is the output. The selection of acceleration in the x and z directions as inputs for the Mamdani fuzzy system, with estimated time as the output, is based on the understanding that acceleration data in different directions can provide comprehensive information about the movement dynamics, which in turn can be effectively utilized to estimate the time required to reach a destination accurately, as shown in Fig. 3.

Then, by observing the relationship of the data with reference to the membership function, the following rule has been developed, as shown in Table 2.

Table 2. Fuzzy Rule

		Acceleration at Z-axis		
		Slow	**Normal**	**Fast**
Acceleration at X-axis	**Slow**	Slow	Normal	Normal
	Normal	Normal	Normal	Normal
	Fast	Normal	Normal	Fast

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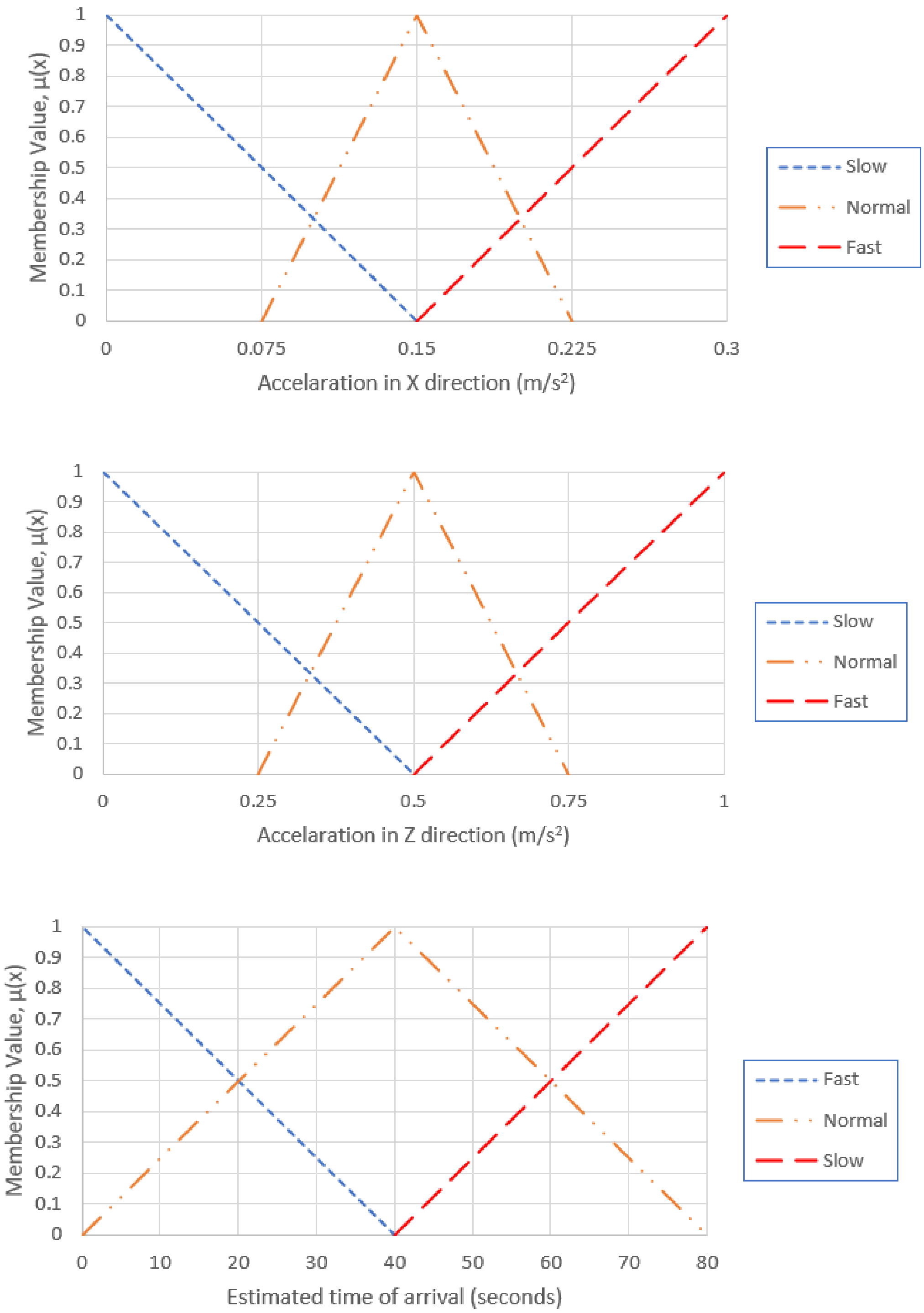

Figure 3. The membership function for the input and the output of the system.

According to the Mamdani Rule Base, the Fuzzy rule can be read as "If condition A AND condition B, then outcome C." Therefore, we can find the compound value of the membership by finding the minimum value between both conditions. However, the conditions of Normal are overlapping with multiple compound values. This situation can be represented by the OR operator, which can be defined as the maximum value among them in fuzzy logic. The membership value for the triangular function can be calculated using Eq. (1).

$$\mu_A(x) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \\ 0 & x \geq c \end{cases} \tag{1}$$

where a is the lower value, b is the medium value, and c is the higher value with the constraint of $a \leq b \leq c$, while x refers to the current crisp input or output. For the fuzzy inference system, the equation for combining fuzzy propositions according to a fuzzy rule is as follows:

$$\mu_{C1} = \min(\mu_{A1}, \mu_{B1}) \tag{2}$$

$$\mu_C = \max(\mu_{C1}, \mu_{C2}) \tag{3}$$

Eq. (2) is for rule evaluation, where the μ_{A1} and μ_{B1} are the membership functions for condition A and condition B for rule 1 and μ_{C1} and μ_{C2} are the outcome C for rule 1 and rule 2. Eq. (3) is for aggregation, where μ_C is the overall fuzzified output as the output from the aggregation method.

The final crisp value can be found using Eq. (4), the Centre of Sum (CoS), by finding the value of each area and center of the area for each fuzzy set, where x_i is the center of the area and A_i is the area of the fuzzy set.

$$x^* = \frac{\sum_{i=1}^{n} x_i A_i}{\sum_{i=1}^{n} A_i} \tag{4}$$

The architecture of the fuzzy Mamdani for the system is shown in Figure 4.

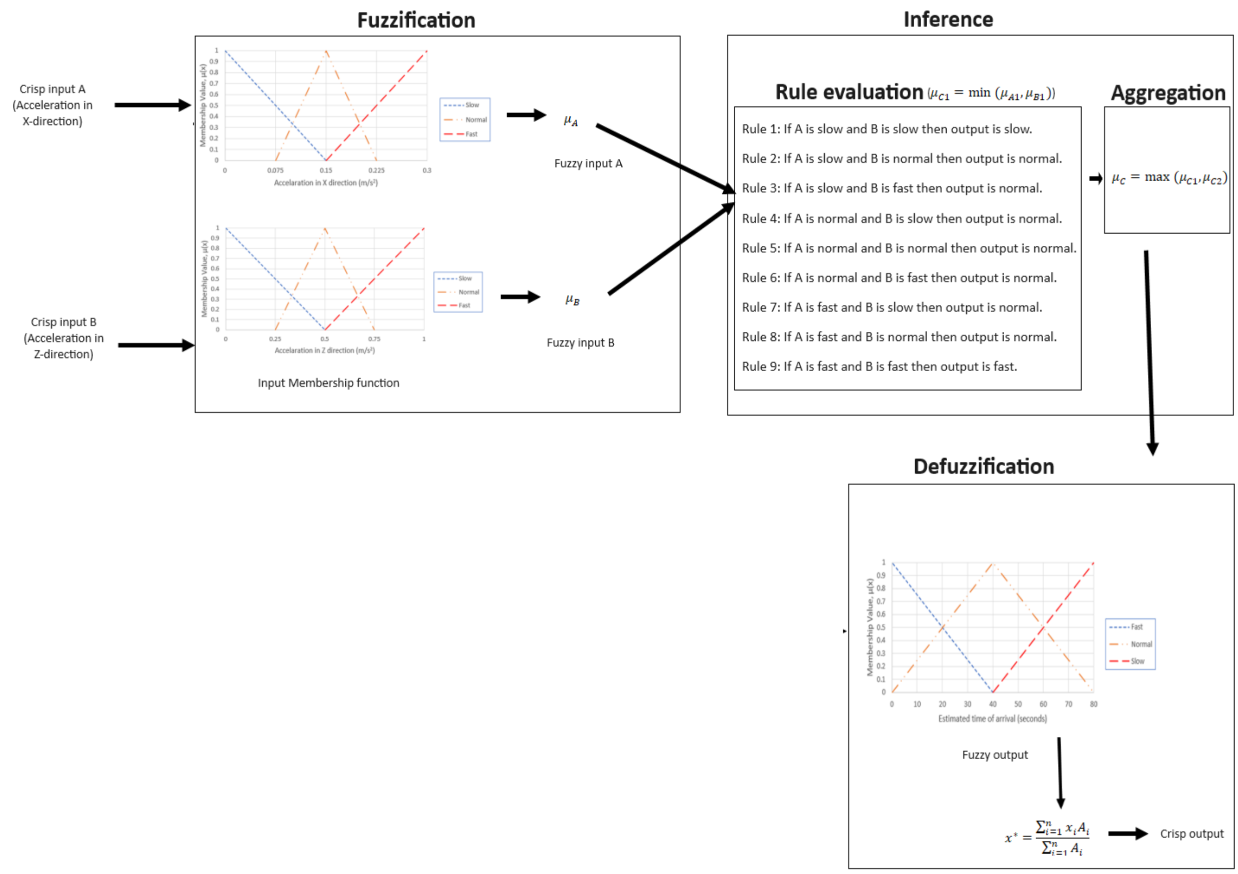

Figure 4. Architecture of fuzzy Mamdani system.

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2.2. Field Test Setup

The first assumption made in the test is that the value of acceleration in the z-direction is always positive as the user moves forward. Initially, the value will always be negative since the pointing direction of the camera is at the negative z-axis. However, since we are moving forward, we will assume it as a positive value. The second assumption is that the acceleration in the y direction does not affect the estimated time of arrival since we are not moving to different floor levels.

The field test is conducted using the same path which is from point A (Dean's Office) to point B (Mechatronics Lab). The time to walk from point A to point B will be recorded as the actual value, while the estimated arrival time is recorded every 2 seconds. Since people usually will not walk with constant acceleration, fluctuating output is expected.

Figure 5. The pathway from point A to point B.

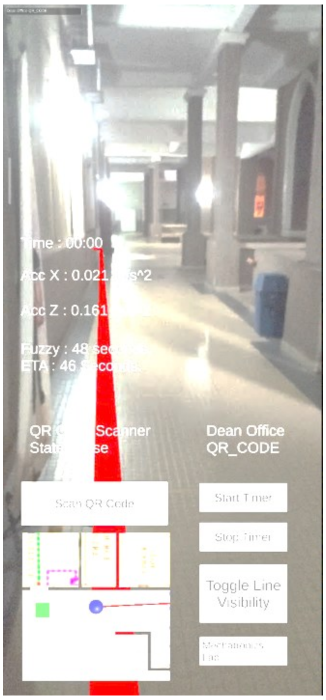

Figure 6. The application interface during a field test.

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3. RESULTS

The performance of the fuzzy logic from the test is evaluated and plotted for the results. The evaluation is mainly on the difference in time required to reach the goal within the estimated time. Figures 7 to 11 contain all the data for the first test and the fifth test. Based on the recorded data, fluctuations in the crisp value could be observed as we were not walking at a constant acceleration. The ETA should have decreased as time passed. However, the output from fuzzy logic does not reflect this behavior as it only predicts the time taken to travel from point A to point B. To ensure that the ETA decreased with time, certain conditions were established, as follows:

1. The starting ETA value will be the same as the crisp value.
2. If the difference between the crisp value and the previous ETA is between 0 and 3 seconds, the new ETA is the difference between the crisp value and the current time.
3. If the difference between the crisp value and the previous ETA is more than 3 seconds, the new ETA is the difference between the previous value and the current time.

For each set of results from Figure 7 to Figure 11, there are three graphs denoted as (a), (b), and (c). In subgraph (a), which displays the acceleration in the x and z directions over time, the movement is depicted in terms of the decomposed acceleration from the actual magnitude into the x and z directions recorded over time. In subgraph (b), which shows the fuzzy logic output over time, the estimated arrival time from the starting point to the goal is indicated over time. Even when in motion and not at the starting point, the fuzzy output will display the estimated arrival time from the starting point. Lastly, in subgraph (c), which presents the estimated time of arrival over time based on real-time data, the estimated time is derived from the current location rather than from the starting point.

The percentage error for each test and the average error are tabulated in Table 3. The error is calculated using Eq. (5), with the experimental value being the estimated time obtained from the fuzzy logic model and the actual value being the duration derived from real-time movement tracking.

$$\%Error = \left|\frac{Experimental\ value - Actual\ value}{Actual\ value}\right| \quad (5)$$

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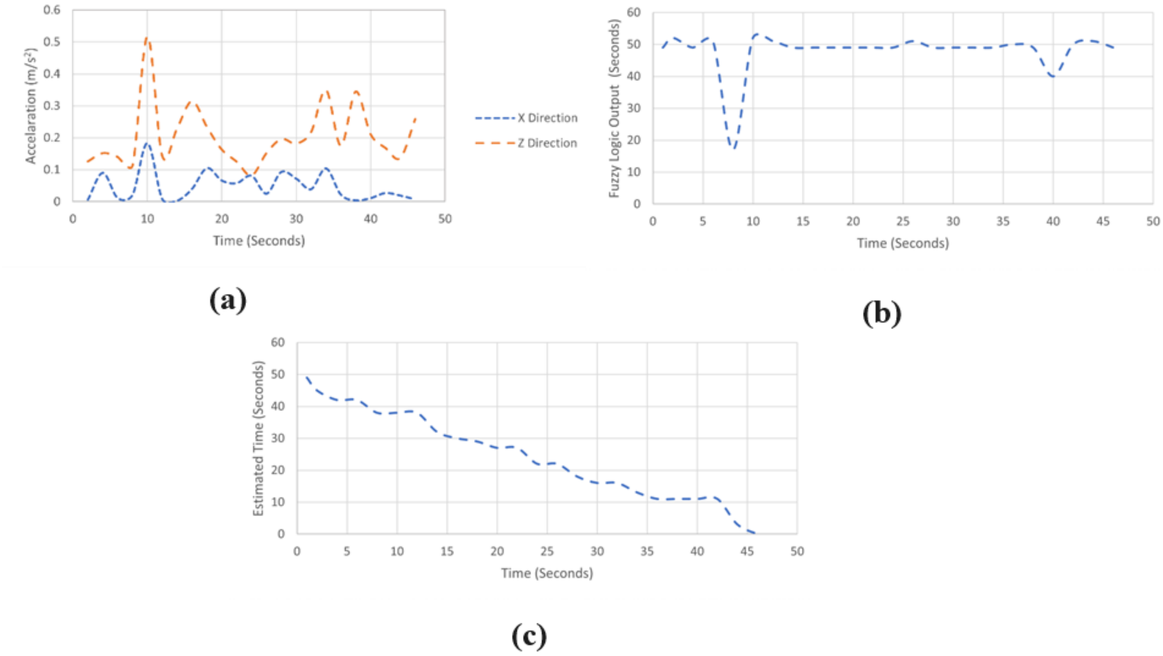


Figure 7. The result of the first test for (a) acceleration in x and z direction over time. (b) fuzzy logic output over time. (c) estimated time over time.

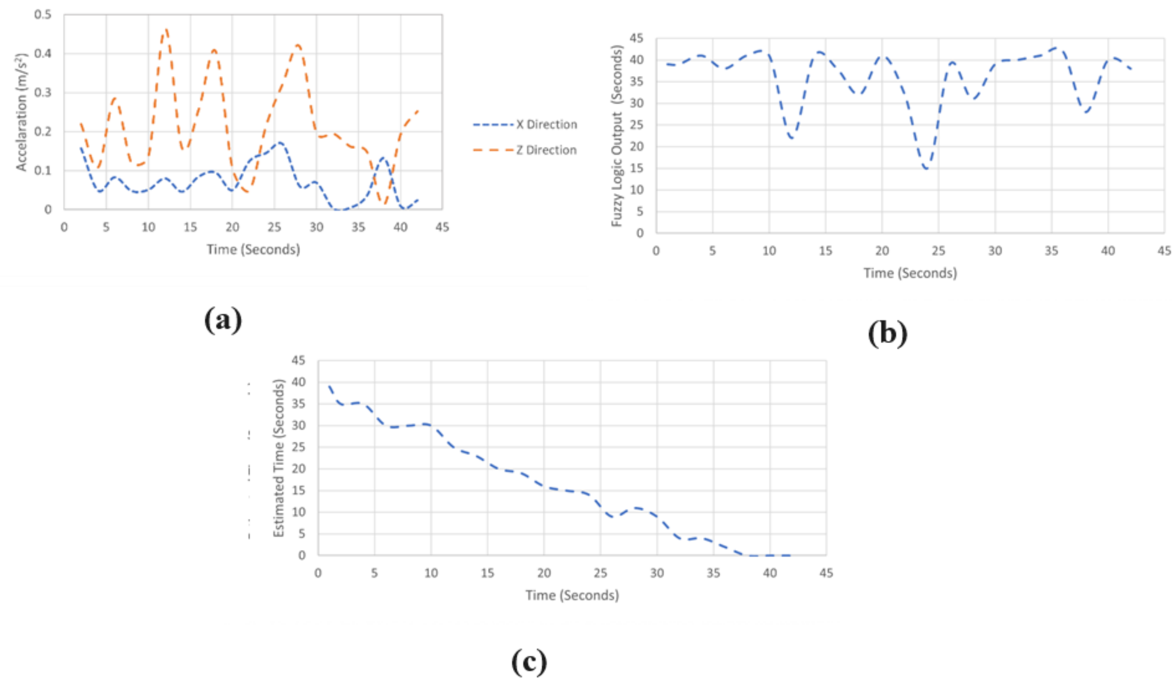
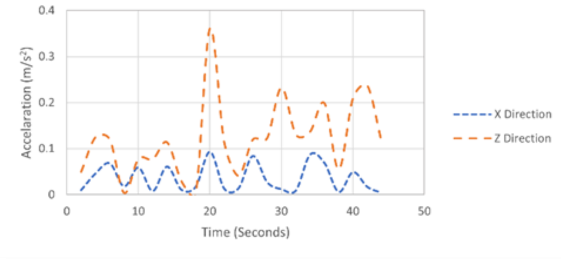
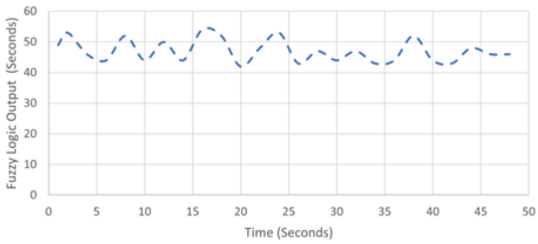


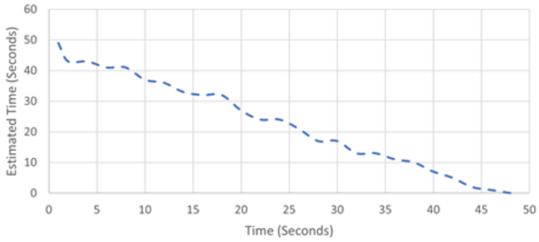
Figure 8. The result of the second test for (a) acceleration in x and z direction over time. (b) fuzzy logic output over time. (c) estimated time over time.



(a)

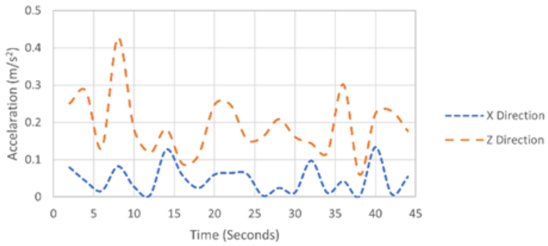


(b)

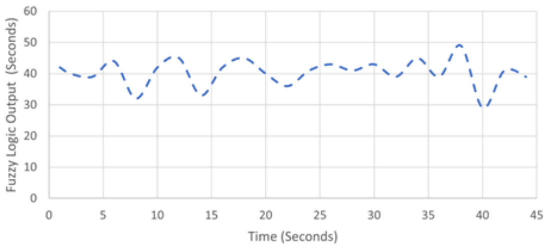


(c)

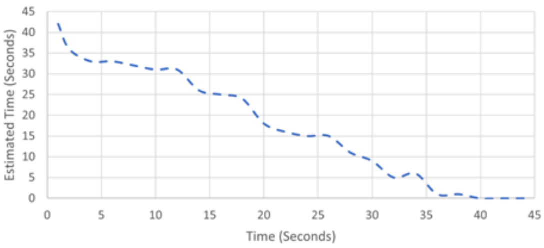
Figure 9. The result of the third test for (a) acceleration in x and z direction over time. (b) fuzzy logic output over time. (c) estimated time over time.



(a)



(b)



(c)

Figure 10. The result of the fourth test for (a) acceleration in x and z direction over time. (b) fuzzy logic output over time. (c) estimated time over time.

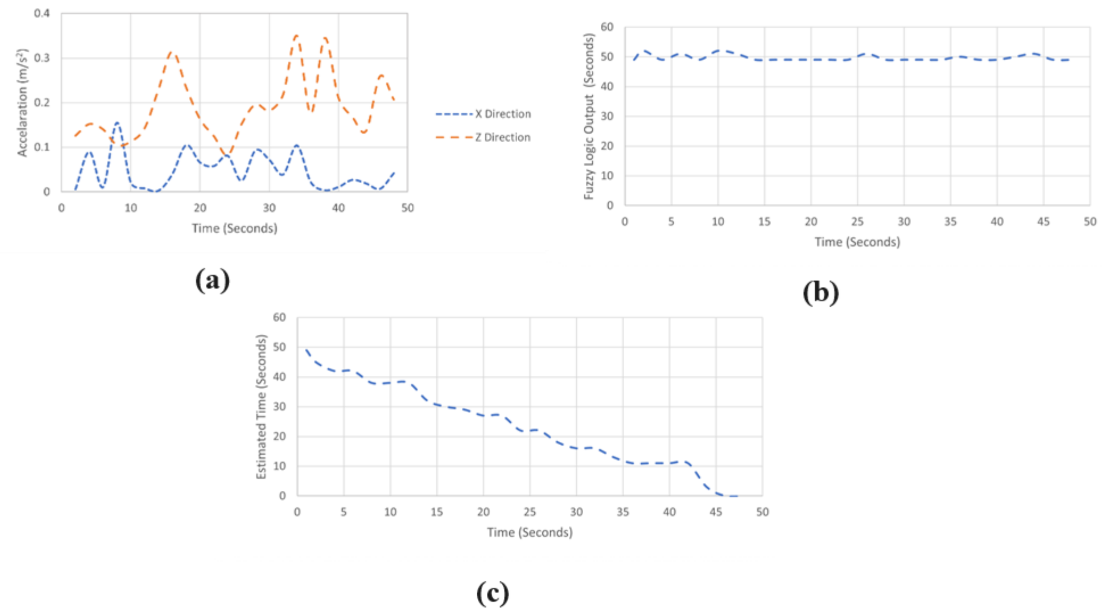


Figure 11. The result of the fifth test for (a) acceleration in x and z direction over time. (b) fuzzy logic output over time. (c) estimated time over time.

Table 3. Calculated percentage of error

Test	Estimated Time(s)	Actual Time(s)	% Error
1	49	46	6.25
2	39	42	7.14
3	40	44	9.09
4	42	44	4.55
5	49	48	2.08
		Average Error	**5.82**

4. DISCUSSION

Based on the results, it is evident that the average error remains at 5.82%, comfortably below the designated maximum threshold of 10%. For accurate estimations in varied locations, constructing diverse membership functions may be imperative to meet specific conditions. Nevertheless, this limitation could be mitigated by integrating fuzzy logic with a neural network, forming a neuro-fuzzy system capable of learning, thereby refining estimations and reducing errors. However, it is important to note that data collection is necessary for training the system. Additionally, potential variation in error arises when different phone models with distinct specifications are employed. Moreover, while using identical phone models, discrepancies may occur due to variations in acceleration readings, particularly if the phone utilized was defective before the experiment commenced. Furthermore, the accuracy of the fuzzy rules may be compromised as the data collection process relies on manual recording, introducing the possibility of human error during data acquisition. While the study demonstrates promising results in arrival time estimation, acknowledging and addressing these limitations is imperative for enhancing the robustness and reliability of the proposed approach in real-world applications.

5. CONCLUSION

In conclusion, the use of intelligent signage in intelligent augmented reality applications has shown promising results in certain cases, highlighting the effectiveness of this approach. Given its use of augmented reality technology to enhance navigation, this method could serve as a viable option for security-related projects. Nonetheless, as the study progresses, researchers may identify some limitations and drawbacks to this approach. The current research mainly used ARCore, which has broader compatibility with different phone models. However, Unity, the platform used for the study, only offers two AR platforms, ARCore and Vuforia, and not all phones are compatible with these platforms, which can make experimentation more challenging. Consequently, this paper offers opportunities for future research. In conclusion, while the study demonstrates promising results in arrival time estimation, acknowledging and addressing these limitations is imperative for enhancing the robustness and reliability of the proposed approach in real-world applications.

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REFERENCES

[1] Fire and Rescue Department. (2020). Statistics On Fire Breakouts, *Statistics On Fire* Breakouts, Malaysia - Dataset - MAMPU. Department of Statistics Malaysia. Retrieved from https://www.data.gov.my/data/en_US/dataset/statistics-on-fire-breakouts-malaysia .

[2] Bahamid, A., Ibrahim, A. M., Ibrahim, A., Zahurin, I. Z., & Wahid, A. N. (2020, December). Intelligent robot-assisted evacuation: A review. In Journal of Physics: Conference Series (Vol. 1706, No. 1, p. 012159). IOP Publishing.

[3] Abir, I. M., Ibrahim, A. M., Toha, S. F., & Shafie, A. A. (2022). A review on the hospital evacuation simulation models. International Journal of Disaster Risk Reduction, 103083

[4] Ibrahim, A. M., Saifullah, M., Romlay, M. R. M., Venkat, I., & Ibrahim, I. (2019, October). Hybrid Social Force-Fuzzy Logic Evacuation Simulation Model For Multiple Exits. In 2019 7th International Conference on Mechatronics Engineering (ICOM) (pp. 1-5). IEEE

[5] Craig, A. B. (2013). Understanding augmented reality: Concepts and applications.

[6] De Oliveira, L. C., Andrade, A. O., De Oliveira, E. C., Soares, A., Cardoso, A., & Lamounier, E. (2017). Indoor navigation with mobile augmented reality and beacon technology for wheelchair users. 2017 IEEE EMBS International Conference on Biomedical and Health Informatics, BHI 2017, 37–40. https://doi.org/10.1109/BHI.2017.7897199

[7] Huang, B. C., Hsu, J., Chu, E. T. H., & Wu, H. M. (2020). Arbin: Augmented reality-based indoor navigation system. Sensors (Switzerland), 20(20), 1–20. https://doi.org/10.3390/s20205890

[8] Matuszka, T., Gombos, G., & Kiss, A. (2013). A new approach for indoor navigation using semantic web technologies and augmented reality. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 8021 LNCS(PART 1), 202–210. https://doi.org/10.1007/978-3-642-39405-8_24

[9] Lo Valvo, A., Croce, D., Garlisi, D., Giuliano, F., Giarré, L., & Tinnirello, I. (2021). A Navigation and Augmented Reality System for Visually Impaired People. Sensors (Basel, Switzerland), 21(9), 1–15. https://doi.org/10.3390/s21093061

[10] Md Noor, R., Seong Yik, N., Kolandaisamy, R., Ahmedy, I., Hossain, M. A., Lim, K.-, Yau, A., Shah, W. M., & Nandy, T. (2020). Predict Arrival Time By Using Machine Learning Algorithm

To Promote Utilization of Urban Smart Bus. February. https://doi.org/10.20944/preprints202002.0197.v1

[11] Liu, Z., Chen, L., Zhou, X., Jiao, Z., Guo, G., & Chen, R. (2023). Machine Learning for Time-of-Arrival Estimation with 5G Signals in Indoor Positioning. 14(8). https://doi.org/10.1109/JIOT.2023.3234123

[12] Bhorkar, G. (2017). A Survey of Augmented Reality Navigation. Retrieved from http://arxiv.org/abs/1708.05006

[13] Koch, C., Neges, M., König, M., & Abramovici, M. (2014). Natural markers for augmented reality-based indoor navigation and facility maintenance. Automation in Construction, 48, 18–30. https://doi.org/10.1016/j.autcon.2014.08.009

[14] Romlay, M. R. M., Rashid, M. M., Toha, S. F., & Ibrahim, A. M. (2019). Rainfall-Runoff Model Based on ANN with LM, BR and PSO as Learning Algorithms. International Journal of Recent Technology and Engineering (IJRTE), 8(3), 971-979.