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Earthquake Damage Estimation Using Fuzzy Logic and Type-2 Fuzzy Logic

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In this study, three different fuzzy logic systems were developed for earthquake damage detection. The first system evaluates the damage status of the building based on various factors, while the second system analyzes the earthquake intensity and ground slope. The third system combines the results of the first two systems to comprehensively evaluate the general status of the building. Both classical fuzzy logic and type-2 fuzzy logic methods were applied separately and successful results were obtained. This structure offers an effective approach in post-earthquake damage detection.

Keywords: *Fuzzy logic, Type-2 Fuzzy logic, Eartquake damage detection, Earthquake intensity, Ground slope*

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1. Introduction

The Middle East has been subjected to many earthquakes since the 2000s, and their magnitudes range from moderate to major. This has affected the geography and demographics of the region. Finally, the earthquake in Kahramanmaraş province caused the deaths of tens of thousands of people and the migration of people.

In such earthquake disasters, many mistakes have been made, such as incorrectly assessing damaged buildings as intact, which has negatively affected the lives of people living in the buildings. Therefore, alternative systems need to be developed to correctly assess the damages caused by these earthquake effects.

Considering the successful results of artificial intelligence technologies, the fuzzy logic method was chosen in this study. This method was chosen because it provides high accuracy in calculating the results.

In the studies conducted so far, the optimum bitumen amount estimation of hot bituminous mixtures produced using concrete and marble wastes using the fuzzy logic method [1], the effect of blast furnace slag on the flexural strength of Portland cement [2], the estimation of the number of Covid-19 deaths in Turkey [3], the estimation of the cooking rate of meat in the gastronomy field [4], the estimation of the unconfined compressive strength [5], the estimation of coal seam methane content [6], the estimation of the risk of traffic accidents [7], the estimation of the popularity of social media news [8] and the estimation of the housing price [9] have been carried out.

In this study, the fuzzy logic structure was used for earthquake damage detection. Three different fuzzy logic structures were used. The first system was used to evaluate the damage of the building through various factors. The second system was used to evaluate the intensity of the earthquake and the slope of the ground under the building. The third system evaluates the condition of the building based on the results obtained from the previous two systems. Fuzzy logic and type-2 fuzzy logic methods were applied separately for earthquake damage detection.

2. Fuzzy Logic

Fuzzy logic is considered one of the most important types of artificial intelligence and is a mechanical reasoning system.

The term "fuzzy" refers to things that are uncertain or unclear. While probabilities are expressed as 0 or 1, which expresses the existence or absence of something, fuzzy logic offers a chance to evaluate within a certain range and is based on certain evaluation results. This means that decisions can be made in line with the results and makes a decision close to the truth in cases that do not exactly match the entered probabilities.

2.1. Fuzzy logic model for earthquake damage estimation

This system is designed to include most of the elements that are effective in evaluating earthquake-induced building damage and consists of three different fuzzy logic systems. The first fuzzy logic system is responsible for evaluating structural building damage and is based on various inputs such as concrete quality, dilatation distance, building age, external wall ratio, number of floors and physical condition of the building. The second system is responsible for evaluating the damage on the ground and the earthquake intensity. It includes five different inputs such as earthquake magnitude, distance to the rupture line, ground slope, orientation according to the rupture line and ground properties. The third system is responsible for evaluating the outputs of the previous two systems, performing the matching according to the applied rules and producing the results. The block diagrams containing the information of the designed fuzzy logic structures are given below.

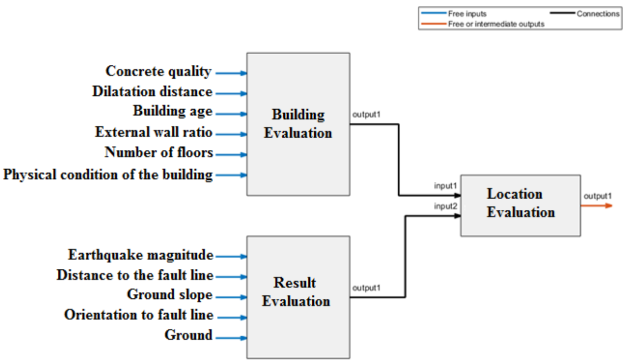

Fig.1. Input and output parameters of the system

Fuzzy logic is formed by two different systems such as Mamdani and Sugeno. These systems are considered as one of the most important and sensitive systems and the method of calculating the probability of each membership function can be controlled by the method of calculating the final result. Gaussian membership function is preferred due to its properties such as symmetry, guard and slope adjustment and is considered as an important function in mathematical data analysis.

The building age is between [0 30] years and the number of floors is between [0 25] floors. Other entries are set to be between [0 1].

2.1.1. Classical fuzzy logic design

The membership function inputs used in the classical fuzzy logic structure for building evaluation are given in Figure 2.

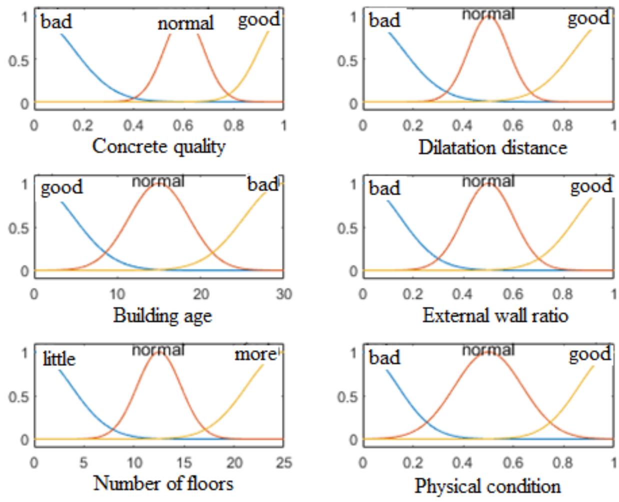

Fig.2. Classical fuzzy logic membership function inputs for building evaluation

- If the concrete quality is normal, the dilatation distance is good, the building age is good, the external wall ratio is normal, the number of floors is low and the physical condition is normal, the building assessment will be considered as very low damage.
- If the concrete quality is normal, the dilatation distance is normal, the building age is good, the external wall ratio is good, the number of floors is normal and the physical condition is good, the building assessment will be considered as low damage.
- If the concrete quality is bad, the dilatation distance is good, the building age is normal, the external wall ratio is good, the number of floors is normal and the physical condition is normal, the building assessment will be considered as normal damage.
- If the concrete quality is bad, the dilatation distance is bad, the building age is normal, the external wall ratio is normal, the number of floors is high and the physical condition is normal, the building assessment will be considered as high damage.
- If the concrete quality is bad, the dilatation distance is bad, the building age is bad, the external wall ratio is bad, the number of floors is high and the physical condition is bad, the building assessment will be considered as very high damage.

The membership function inputs used in the classical fuzzy logic structure for for location evaluation are given in Figure 3.

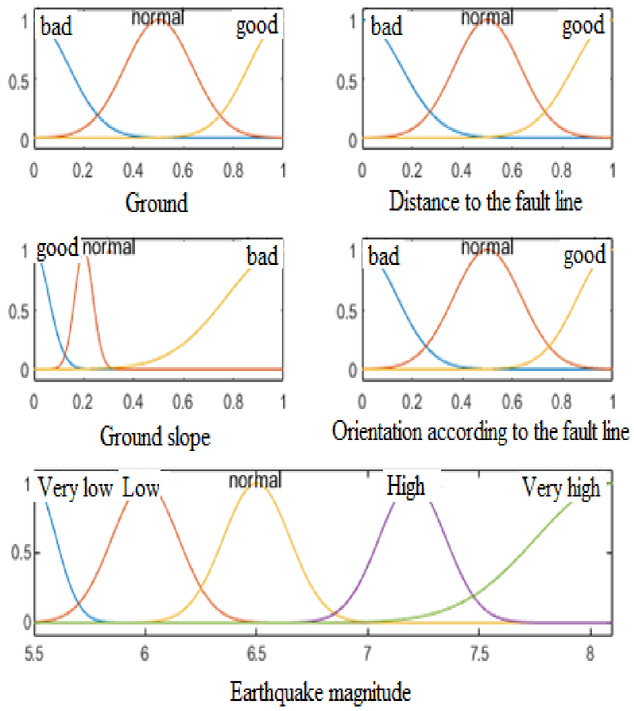

Fig.3. Classical fuzzy logic membership function inputs for location evaluation

- ❖ If the earthquake magnitude is very low, the distance to the fracture line is good, the ground slope is good, the orientation to the fracture line is good and the ground is good, the site assessment will be considered very low damage.
- ❖ If the earthquake magnitude is low, the distance to the fracture line is bad, the ground slope is normal, the orientation to the fracture line is good and the ground is good, the site assessment will be considered low damage.
- ❖ If the earthquake magnitude is normal, the distance to the fracture line is normal, the ground slope is normal, the orientation to the fracture line is normal and the ground is normal, the site assessment will be considered normal damage.
- ❖ If the earthquake magnitude is high, the distance to the fracture line is normal, the ground slope is good, the orientation to the fracture line is good and the ground is bad, the site assessment will be considered high damage.
- ❖ If the earthquake magnitude is very high, the distance to the fracture line is bad, the ground slope is good, the orientation to the fracture line is good and the ground is bad, the site assessment will be considered very high damage.

The outputs of building evaluation and site evaluation are used as inputs of the decision-making mechanism. Classical type fuzzy logic membership function inputs for the decision-making mechanism are shown below.

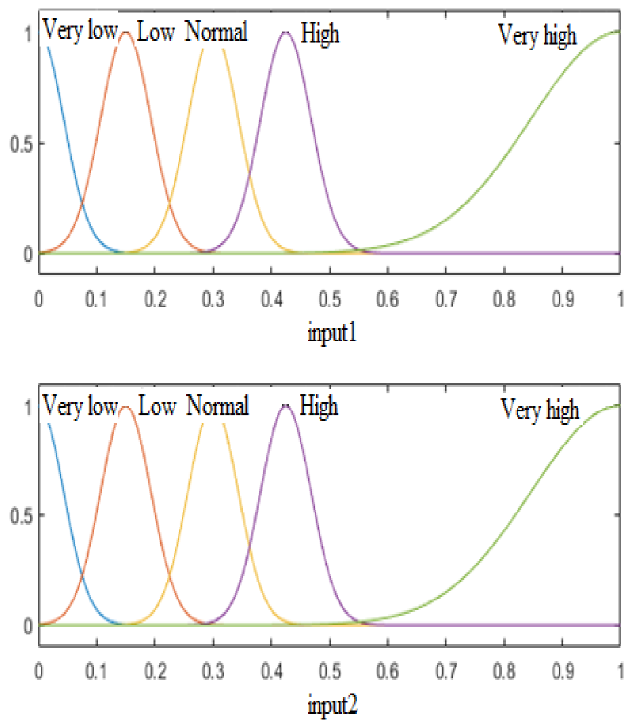

Fig.4. Classical type fuzzy logic membership function inputs for decision making mechanism

- ❖ If the building assessment is very low and the location assessment is very low, it will be considered very low damage.
- ❖ If the building assessment is low and the location assessment is very low, it will be considered low damage.
- ❖ If the building assessment is low and the location assessment is normal, it will be considered normal damage.
- ❖ If the building assessment is high and the location assessment is normal, it will be considered high damage.
- ❖ If the building assessment is high and the location assessment is very high, it will be considered very high damage.

Figure 5 displays the classical type fuzzy logic membership function outputs of the decision-making mechanism.

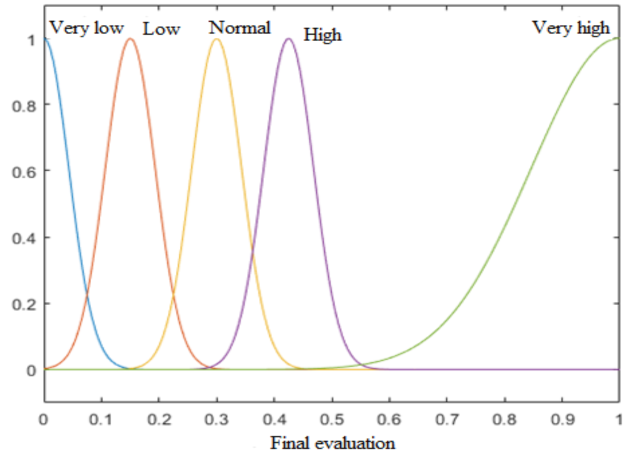

Fig.5. Classical type fuzzy logic membership function outputs of the decision-making mechanism

2.1.2. Type-2 fuzzy logic design for earthquake damage detection

Fuzzy Logic is a type of fuzzy logic system, also called the second type (Type-2) fuzzy logic. This system considers the level of uncertainty in more detail in addition to standard fuzzy logic systems. Type-2 fuzzy logic, unlike traditional fuzzy logic systems, has the ability to provide more information under any uncertainty. All membership functions are approximately determined according to the effect of each element on the durability of the building. For example, the area of concrete quality appears to be larger than the number of floors because concrete quality is affected more by the number of floors.

Type-2 fuzzy logic membership function inputs for building evaluation are shown in Figure 6.

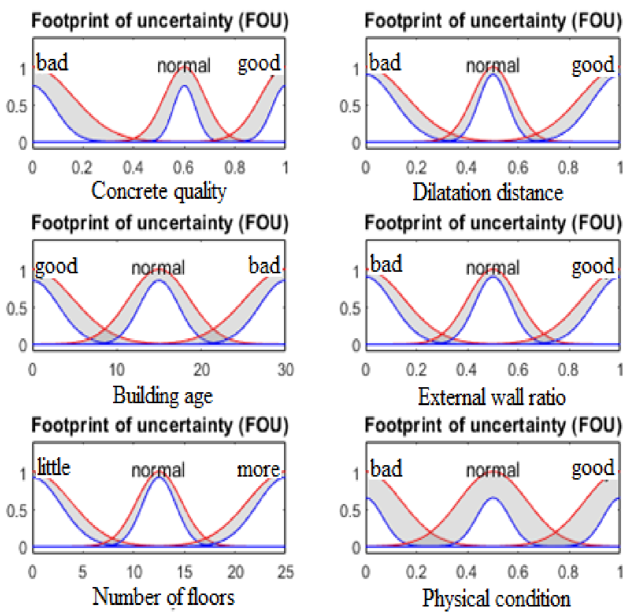

Fig.6. Type-2 fuzzy logic membership function inputs for building evaluation

In Figure 7, Type-2 fuzzy logic membership function inputs for location evaluation are presented.

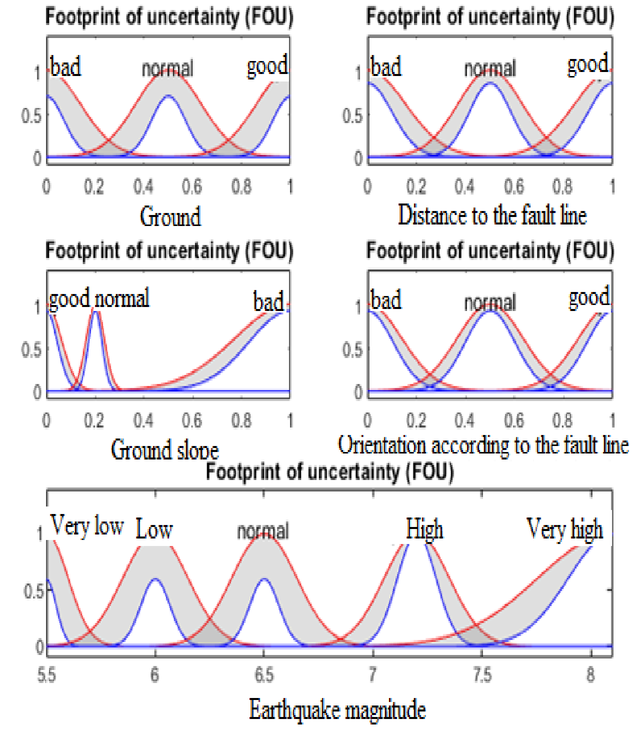

Fig.7. Type-2 fuzzy logic membership function inputs for location evaluation

Figure 8 shows the Type-2 fuzzy logic membership function inputs for the decision-making mechanism in detail.

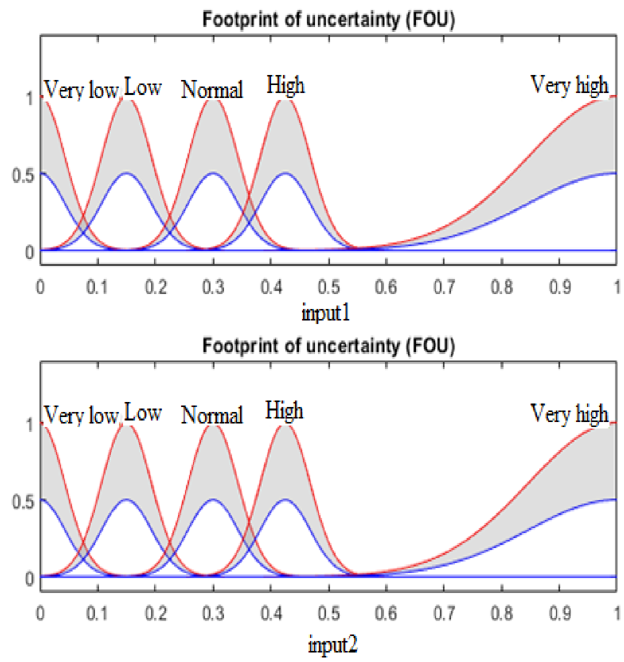

Fig.8. Type-2 fuzzy logic membership function inputs for the decision-making mechanism

Figure 9 shows the Type-2 fuzzy logic membership function outputs of the decision-making mechanism.

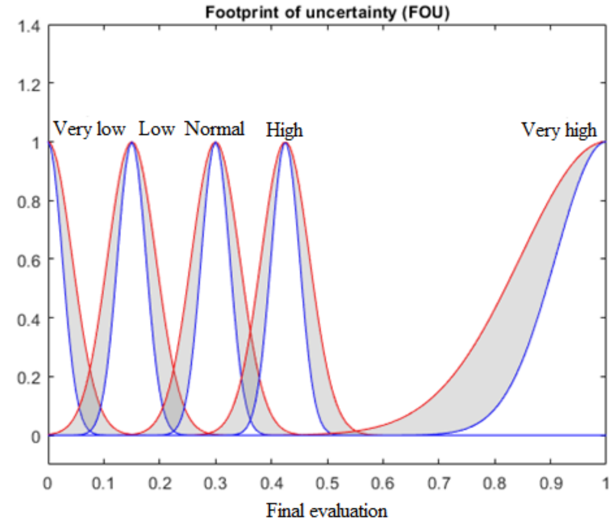

Fig.9. Type-2 fuzzy logic membership function outputs of the decision-making mechanism

2.2. Damage detection interface

The interface is designed in MATLAB environment, which makes it easier to use all systems together. There are four systems to calculate the building damage rate; two are designed with the mamdani system and two are designed with the sugeno system. The interface calculates the damage rate in each system and calculates the final result by summing the results using a specific algorithm. The interface also includes an auxiliary system to understand how to enter the value and prints the results as the final result with the value input. Figure 10 shows damage detection interface.

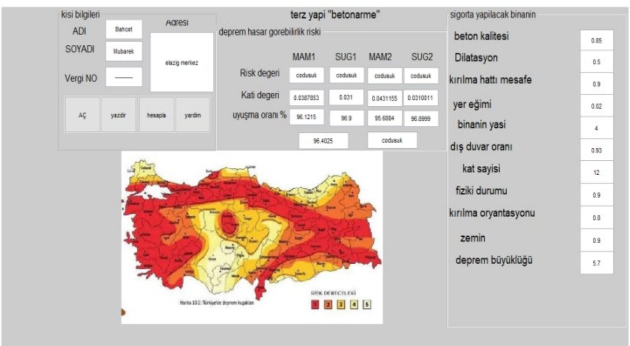

Fig.10. Damage detection interface

When the help button is pressed, a list of all the inputs and their areas is displayed. The areas available are thus listed in relative order, with the exception of the building age and number of floors, as the results measured by the devices may differ. For example, when measuring concrete quality, there are various types of concrete, and therefore the quality is measured proportionally according to the type of concrete.

3. Conclusion

In this study, a system is created to evaluate the building hazard status. This system is created on the principle of a committee of four experts, each system evaluates the building status in a certain way. The difference in each system is due to the difference in the rules applied to the system. Therefore, the results of the first type may differ in Mamdani and Sugeno systems, while the effect of the inputs in the second type of Sugeno and Mamdani systems may vary according to the durability and strength of the building. Therefore, the results of the second type are more accurate than the results of the first type.

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