A FUZZY LOGIC APPROACH FOR DRONE CAPABILITY ANALYSIS ON DISASTER RISK ASSESSMENT

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ABSTRACT:

The paper proposes a fuzzy logic approach for drone capability analysis on disaster risk assessment. In particular, a fuzzy logic model is designed as a hierarchical system with several inputs and one output. The system inputs corresponds to the linguistic variables, describing the of levels of the external and internal input factors, which determine the capability levels of analysed drone in respect to disaster risk assessment. As external input factors are used, for example: disaster type (flood, landslide, wildfire); weather conditions (wind speed, fog, cloud cover); operational area (urban, mountain, plain), etc. As internal input factors are considered the drone characteristics such as drone type, flight performance (stall speed, turn radius, flight endurance), payload capabilities (camera resolution, accuracy, weight, sensors), etc. The fuzzy logic system output gives the level of the drone capability on disaster risk assessment in defined conditions. The model is designed in *Matlab* computer environment using Fuzzy Logic Toolbox. Several computer simulations are carried out to validate the proposed model. The designed fuzzy logic model is part of an information system for disaster risk management using drones, which is under development.

1. INTRODUCTION

In recent years, there has been an increase in the number and strength of natural and man-made disasters worldwide (Fachot, 2017). For these reasons, the disaster risk assessment is becoming more and more relevant (UNISDR, 2015, 2019).

Studies have shown that the drones (or unmanned aerial vehicle - UAV) can be successfully used in disaster risk assessment (Mazur et al., 2017; Nelson Jr., 2017; Srinivasan, 2018). Key role to their success is the huge variety of shapes and sizes. At all phases of disaster management (preparedness, response, recovery and reconstruction) one of the first actions to be taken is establish a disaster management headquarter for coordination. This is where drones come in packed up with sensors. Drones may bring significant improvements with respect to these issues. Depending on the requirements of their potential mission, they deliver huge sensor scanning capabilities along with ever increasing performance in terms of control. There are also limitations in the sensor performance in different environment conditions (for example, no observation at night or in presence of cloud cover).

Drones also have drawbacks and cannot be operated at all time. First, they have to cope with weather conditions at a higher degree than conventional aircrafts: because of their light weight and rather low propulsive power, they are more sensitive to wind gusts, for instance. Secondly, they are less prepared to face difficult environments, such as heavy rain (water-proof conception) or hot temperatures. Therefore, these basic conditions have to be checked prior to operating them.

There are different drones for a wide range of applications with different sizes. Drones can be classified in many ways: Use (civil vs military), Lift (fixed-wing vs multi-rotors), MTOW (maximum take-off weight), etc. Drones could be usefully classified based on their size and payload since those are essential features from a functional point of view (ARC, 2015).

While platforms dictate the drone's ability to access certain environments, its payload often determines the type of data it can collect. Remote sensors like Electro-Optical (EO) and Infrared (IR) (EO/IR) cameras can help establishing situation-awareness while communications relay payloads can be used to broadcast wireless frequencies wherever the drone travels.

The drones as a type of aircraft, will always be subject of the weather and environmental conditions. Severe weather conditions (high winds, icing, etc.) may ground the use of drones for indefinite period. In addition, environmental factors play a role in sensor effectiveness. Smoke from wildfire or wreckage obscure the sensors restricting their performance, while microbursts can inflict drones' flight.

It is also necessary to consider the flight characteristics of the drones in different environments, for example in tight areas and urban canyons drone with smaller turn radius. Different areas require different sensor characteristics – crops field or high plateau need lesser performance than buildings and urban sites.
All this considered, the drone is capable of maintaining the observation or not.
Atmospheric conditions can have significant impact on EO and IR performance.

The purpose of the paper is to propose a fuzzy logic approach for drone capability analysis on disaster risk assessment. In particular, a fuzzy logic model is designed as a hierarchical system with several inputs and one output. The system inputs corresponds to the linguistic variables, describing the of levels of the external and internal input factors, which determine the capability levels of analysed drone in respect to disaster risk assessment.

2. FUZZY LOGIC MODEL FOR DRONE CAPABILITY ANALYSIS ON DISASTER RISK ASSESSMENT

The general idea is to propose a fuzzy logic model for drone capability analysis on disaster risk assessment. The fuzzy logic model is designed as a hierarchical system with several inputs and one output.

The system inputs corresponds to the linguistic variables (indicators), describing the of levels of the external and internal input factors, which determine the capability levels of analysed drone in respect to disaster risk assessment. As external input factors are used different indicators: disaster type (flood, landslide, wildfire); weather conditions (wind speed, fog, cloud cover); operational area (urban, mountain, plain), etc. As internal input factors are considered the drone characteristics such as drone type, flight performance (stall speed, turn radius, flight endurance), payload capabilities (camera resolution, accuracy, weight, sensors), etc. The fuzzy logic system output gives the level of the drone capability on disaster risk assessment in defined conditions.

In this study, the fuzzy logic model is designed as a three-level hierarchical system with seven inputs and one output. The proposed fuzzy logic system includes six fuzzy logic subsystem. Each fuzzy logic subsystem has two inputs and one output. The output of the sixth subsystem is output of the whole fuzzy logic system. A scheme of this three-level hierarchical fuzzy system is presented on Figure 1.

The rules for logical inference in designed fuzzy logic subsystems are defined on the basis of research theoretical studies and real expertise with different drones.

The values for input variables (indicators) are determined using expert knowledge, specific geoinformation, thematic maps, on-line and archive hydrological and meteorological data, etc.

Here, the seven input variables (indicators) of the fuzzy system are defined as follow:

- Input 1 „*Flight time*” (The maximum allowable flying time of the investigated drone);
- Input 2 „*Relief*” (The relief of the area affected by a disaster: urban, mountain, plain, etc.);
- Input 3 „*Ceiling*” (The ceiling of the investigated drone);
- Input 4 „*Visibility*” (The visibility above the area affected by a disaster, which is determined by the presence of fog, rainfall, cloud cover, snow, etc.);
- Input 5 „*Payload*” (The payload of the investigated drone: camera /resolution, accuracy, weight/, different types of sensors, etc.);
- Input 6 „*Wind*” (The wind in the area affected by a disaster);
- Input 7 „*Wind resistance*” (The wind resistance of the investigated drone).

Five intermediate linguistic variables are defined in the designed model. These intermediate variables are the outputs of the five fuzzy logic subsystems (*Output 1, Output 2, Output 3, Output 4, Output 5*).

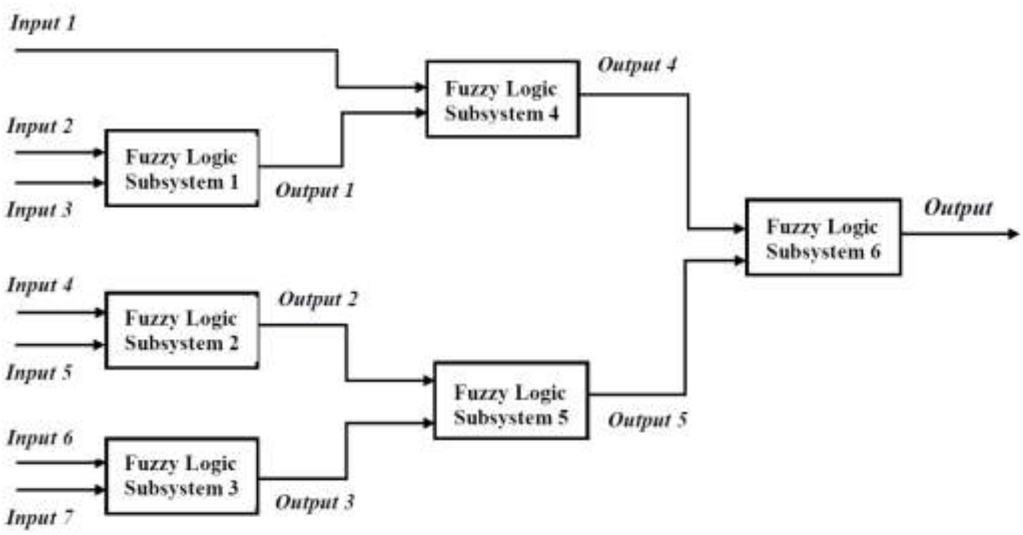

Figure 1. Three-level hierarchical fuzzy logic system

In proposed model, the inputs of the first fuzzy logic subsystem are Input 2 „*Relief*” and Input 3 „*Ceiling*”, and the output variable is the Intermediate variable 1 “*Output 1*".

The inputs of the second fuzzy logic subsystem are Input 4 „*Visibility*” and Input 5 „*Payload*”, and the output variable is the Intermediate variable 2 “*Output 2*".

The inputs of the third fuzzy logic subsystem are Input 6 „*Wind*” and Input 7 „*Wind resistance*”, and the output variable is the Intermediate variable 3 “*Output 3*".

The inputs of the fourth fuzzy logic subsystem are Input 1 „*Flight time*” and Intermediate variable 1 “*Output 1*", and the output variable is the Intermediate variable 4 “*Output 4*".

The inputs of the fifth fuzzy logic subsystem are Intermediate variable 2 “*Output 2*" and Intermediate variable 3 “*Output 3*", and the output variable is the Intermediate variable 5 “*Output 5*".

The inputs of the sixth fuzzy logic subsystem are Intermediate variable 4 “*Output 4*" and Intermediate variable 5 “*Output 5*", and the output variable is the fuzzy logic system output “*Output*" (The level of the drone capability on disaster risk assessment in defined conditions).

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The higher value of the fuzzy logic system output “*Output*" corresponds to the higher level of the drone capability on disaster risk assessment in defined conditions. This value can be used as a criterion for informative decision making about the selection of the most suitable drone for disaster risk assessment.

3. DESIGN OF THE FUZZY LOGIC MODEL FOR DRONE CAPABILITY ANALYSIS ON DISASTER RISK ASSESSMENT

In this study, the input linguistic variables (the seven indicators and five intermediate) are defined by different fuzzy membership functions. The all input variables are assessed in the interval [0, 10] using trapezoid membership functions.

The membership functions are described, as follow:

- Input 1 „*Flight time*” is described by three fuzzy membership functions: “Low“, “Middle”, “High” (Fig. 2);
- Input 2 „*Relief*” is described by five fuzzy membership functions: “Very low”, “Low“, “Middle”, “High”, “Very high” (Fig. 3);
- Input 3 „*Ceiling*” is described by four fuzzy membership functions: “Low“, “Middle”, “High”, “Very high” (Fig. 4);
- Input 4 „*Visibility*” is described by five fuzzy membership functions: “Very low”, “Low“, “Middle”, “High”, “Very high” (Fig. 5);
- Input 4 „*Payload*” is described by five fuzzy membership functions: “Very low”, “Low“, “Middle”, “High”, “Very high” (Fig. 6);
- Input 6 „*Wind*” is described by four fuzzy membership functions: “Low“, “Middle”, “High”, “Very high” (Fig. 7);
- Input 7 „*Wind resistance*” is described by three fuzzy membership functions: “Low“, “Middle”, “High” (Fig. 8).

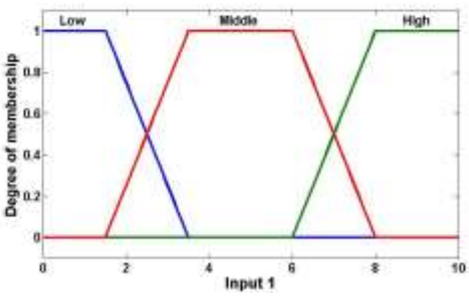

Figure 2. Membership functions of the Input 1

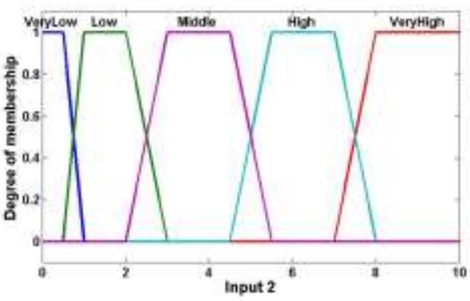

Figure 3. Membership functions of the Input 2

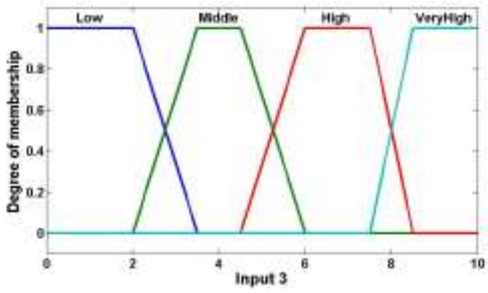

Figure 4. Membership functions of the Input 3

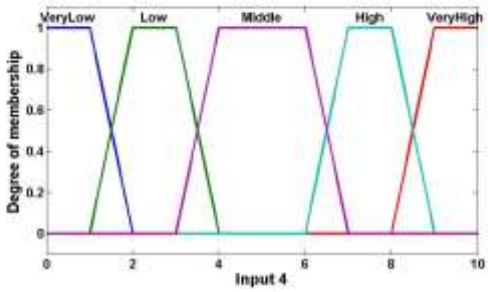

Figure 5. Membership functions of the Input 4

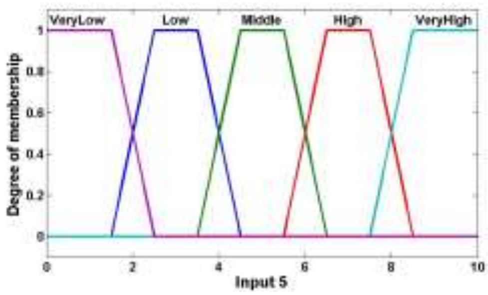

Figure 6. Membership functions of the Input 5

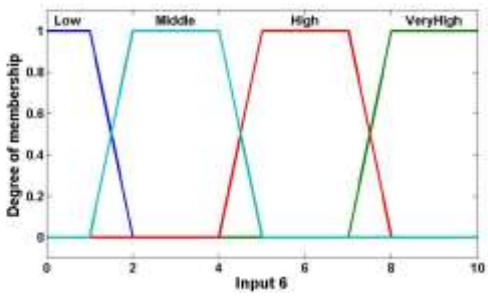

Figure 7. Membership functions of the Input 6

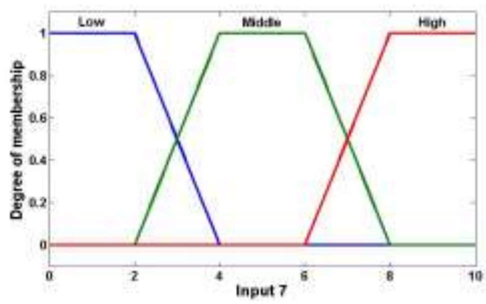

Figure 8. Membership functions of the Input 7

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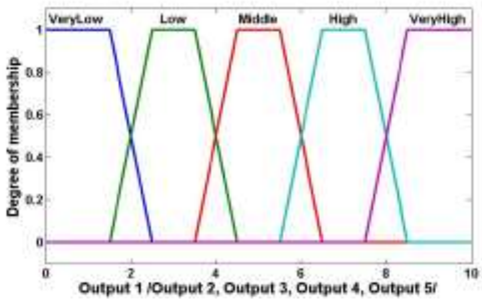

Figure 9. Membership functions of the Input 7

The fuzzy logic system output "*Output*" (*The level of the drone capability on disaster risk assessment in defined conditions*) is described by five fuzzy membership functions: "Very low", "Low", "Middle", "High", and "Very high". The level of the drone capability on disaster risk assessment in defined conditions is assessed in the interval [0, 100] using trapezoid membership functions (Fig. 10).

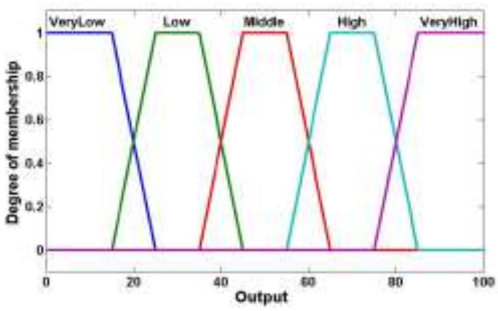

Figure 10. Membership functions of the fuzzy system output.

The inference rules in the fuzzy logic system are defined through "IF - THEN"-clause. The number of rules in the knowledge base (fuzzy logic matrix) for each of the six fuzzy logic subsystems (FLS) is the following: FLS 1 – 20, FLS 2 – 25, FLS 3 – 12, FLS 4 – 15, FLS 5 – 25, FLS 6 – 25. Some of the inference rules are defined as follow:

IF „*Relief*" is "Low" and "*Ceiling*" is "Very high" THEN "*Intermediate variable 1 - Output 1*" is "Very high";

IF „*Relief*" is "Middle" and "*Ceiling*" is "High" THEN "*Intermediate variable 1 - Output 1*" is "High";

IF „*Relief*" is "High" and "*Ceiling*" is "Low" THEN "*Intermediate variable 1 - Output 1*" is "Very low";

IF „*Visibility*" is "Very low" and "*Payload*" is "Low" THEN "*Intermediate variable 2 - Output 2*" is "Very low";

IF „*Visibility*" is "Low" and "*Payload*" is "High" THEN "*Intermediate variable 2 - Output 2*" is "Middle";

IF „*Visibility*" is "Middle" and "*Payload*" is "Low" THEN "*Intermediate variable 2 - Output 2*" is "Low";

IF „*Wind*" is "Low" and "*Wind resistance*" is "High" THEN "*Intermediate variable 3 - Output 3*" is "Very high";

IF „*Wind*" is "High" and "*Wind resistance*" is "Low" THEN "*Intermediate variable 3 - Output 3*" is "Very low";

IF „*Wind*" is "Very high" and "*Wind resistance*" is "Middle" THEN "*Intermediate variable 3 - Output 3*" is "Low";

IF „*Flight time*" is "Low" and "*Intermediate variable 1 - Output 1*" is "Very high" THEN "*Intermediate variable 4 - Output 4*" is "Middle";

IF „*Flight time*" is "Middle" and "*Intermediate variable 1 - Output 1*" is "Low" THEN "*Intermediate variable 4 - Output 4*" is "Low";

IF „*Flight time*" is "High" and "*Intermediate variable 1 - Output 1*" is "High" THEN "*Intermediate variable 4 - Output 4*" is "Very high";

IF „*Intermediate variable 2 - Output 2"* is "Very low" and "*Intermediate variable 3 - Output 3*" is "Low" THEN "*Intermediate variable 5 - Output 5*" is "Very low";

IF „*Intermediate variable 2 - Output 2"* is "High" and "*Intermediate variable 3 - Output 3*" is "Low" THEN "*Intermediate variable 5 - Output 5*" is "Middle";

IF „*Intermediate variable 2 - Output 2"* is "Very high" and "*Intermediate variable 3 - Output 3*" is "High" THEN "*Intermediate variable 5 - Output 5*" is "Very high";

IF „*Intermediate variable 4 - Output 4"* is "Low" and "*Intermediate variable 5 - Output 5*" is "Very low" THEN "*Output*" is "Very low";

IF „*Intermediate variable 4 - Output 4"* is "Low" and "*Intermediate variable 5 - Output 5*" is "High" THEN "*Output*" is "High";

IF „*Intermediate variable 4 - Output 4"* is "Middle" and "*Intermediate variable 5 - Output 5*" is "Low" THEN "*Output*" is "Low";

IF „*Intermediate variable 4 - Output 4"* is "High" and "*Intermediate variable 5 - Output 5*" is "Very high" THEN "*Output*" is "Very high";

The fuzzy logic hierarchical system is designed in Matlab environment using Fuzzy Logic Toolbox (Mathworks, 2014). The six fuzzy subsystems is based on Mamdani's inference machines (fuzzy logic matrix). The models use max/min operations for fuzzy rules and center of gravity defuzzification.

The inference surfaces in 3D for the six fuzzy logic subsystems are given on Figures 11 - 15.

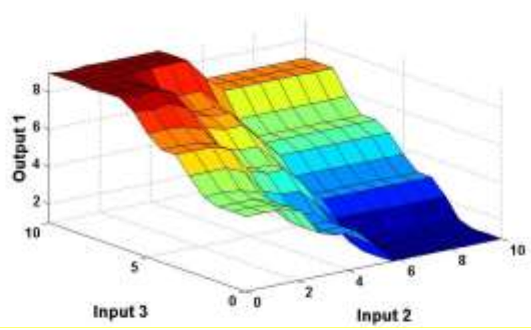

Figure 11. Surfaces of the fuzzy logic subsystem 1.

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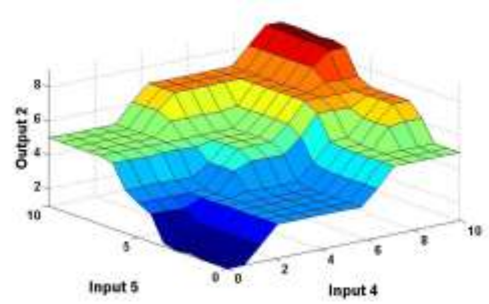

Figure 12. Surfaces of the fuzzy logic subsystem 2.

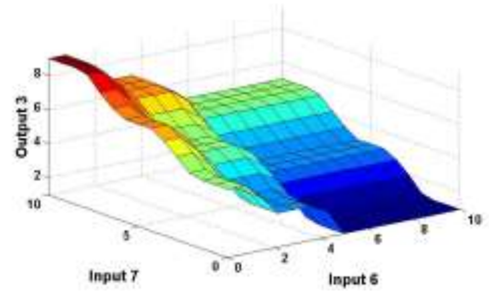

Figure 13. Surfaces of the fuzzy logic subsystem 3.

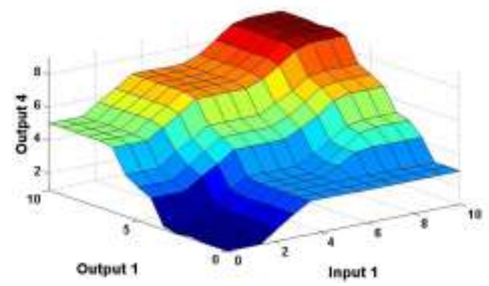

Figure 14. Surfaces of the fuzzy logic subsystem 4.

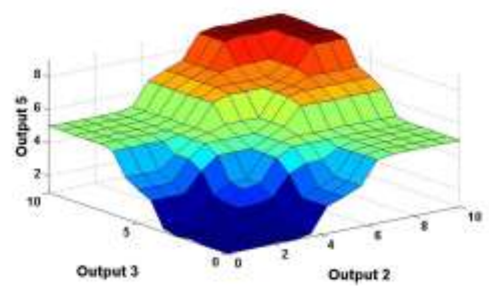

Figure 15. Surfaces of the fuzzy logic subsystem 5.

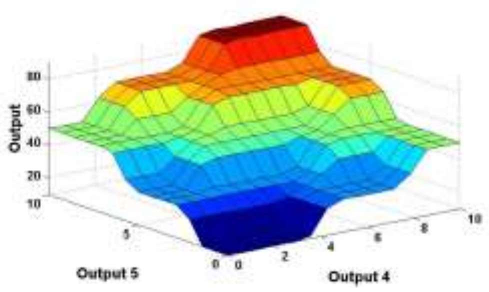

Figure 16. Surfaces of the fuzzy logic subsystem 6.

The interval [0, 100] of the system output variable "*Output*" is divided into five parts to assessment "*The level of the drone capability on disaster risk assessment in defined conditions* " *level of the drone capability* negative social-economic consequences for household or its members because of power outage due to natural disasters:

IF the estimated output value ∈ [0, 20) THEN *the level of the drone capability on disaster risk assessment in defined conditions*" is Very low.

IF the estimated output value ∈ [20, 40) THEN *The level of the drone capability on disaster risk assessment in defined conditions"* is Low.

IF the estimated output value ∈ [40, 60) THEN *The level of the drone capability on disaster risk assessment in defined conditions"* is Middle.

IF the estimated output value ∈ [60, 80) THEN *The level of the drone capability on disaster risk assessment in defined conditions"* is High.

IF the estimated output value ∈ [80, 100] THEN *The level of the drone capability on disaster risk assessment in defined conditions"* is Very high.

Several computer simulations are carried out to validate the proposed fuzzy logic model.

4. CONCLUSIONS

A fuzzy logic model for drone capability analysis on disaster risk assessment is proposed. It is designed as a hierarchical system. The system inputs corresponds to the linguistic variables, describing the of levels of the external and internal input factors, which determine the capability levels of analysed drone in respect to disaster risk assessment. The fuzzy logic system output gives the level of the drone capability on disaster risk assessment in defined conditions. The designed fuzzy logic model is part of an information system for disaster risk management using drones, which is under development.

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