Journal of Electronic Research and Application

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A Self-Powered Energy-Saving Epidemic Prevention Tent

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Abstract: The current situation of the epidemic is complex and changeable. Under the China adherence to the "dynamic zero clearance," epidemic prevention and control is closely related to all walks of life, and epidemic prevention awning has become one of the essential basic epidemic prevention facilities. However, most of the epidemic awnings are manufactured for the isolation and protection from wind and rain, which could not meet the needs of electricity allocation during emergencies. Therefore, our goal is to design a new energy-saving epidemic prevention tent that is green, stable, and easy to shrink. It is equipped with multiple energy storage and multivariate methods to achieve self-supply of electric energy. First the "1+1" arrangement design of solar power panels on the anti-epidemic tent and pressure power panels combined with the design of pressure power panels under the tent can receive various energy inputs. At the same time, retractable brackets are designed under the four pillars, which are easy to fold and enhance the stability of the canopy. The utilization of energy is more diversified to achieve the purpose of energy conservation and emission reduction. Its market value is broad, and the development prospect is good.

Keywords: Anti-epidemic tent; Self-powered energy system; Energy saving and emission reduction; The new model

Online publication: September 28, 2022

1. Introduction

Since the outbreak of COVID-19 in 2020, epidemic prevention and control has become a vital part of everyone's life. In railway stations, airports, and many places where temperature measurement is required to control the flow of people in and out [1], epidemic prevention tents are used with high frequency. Tents that are currently in use are often equipped with infrared temperature measurement and control, disinfection, and other functions [2]. In addition, tents in some areas are also equipped with electric fans and other electrical equipment. However, the majority of tents currently in use in China only have the functions of isolation space, and sun, rain, and lighting protection with relatively single functions. Since the electricity energy technology is an emerging and has wide application prospect in energy technology [3], the super capacitor between conventional capacitors and rechargeable batteries are the new type of energy storage device with both capacitor fast charging and discharging characteristics, at the same time has a battery energy storage property [4], which is very suitable for application in the energy supply system.

2. External structure of the epidemic presentation tent

2.1. The steel parts

The upper part of the pillar structure of the epidemic prevention tent is an umbrella support structure, realizing the function of semi-automatic expansion of the tent. The framework can be expanded and contracted to ensure easy handling of the epidemic cover. All structures have smooth edges, high safety, energy saving, high strength, stable structure, and long service time. The foot support of the epidemic prevention canopy is designed as a retractable support, which presents a triangular structure on the vertical surface after being expanded to enhance the stability of the epidemic prevention canopy. In addition, the brackets can be fully shrunk and folded to facilitate the movement of the epidemic prevention canopy after folding. After the expansion of the two brackets between the feet of 90 degrees, the bottom of the canopy can be further pressed firmly. Compared with the ordinary epidemic prevention awnings with only four pillars, the new epidemic prevention awnings are fixed by sandbagging and other methods when the environment becomes bad. Further, the support structure designed by the new epidemic prevention awnings can ensure the stability of the awnings while realizing the foldable form, easy to carry, and convenient.
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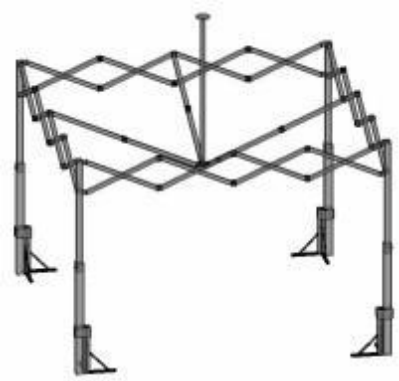

Figure 1. Pillar structure of the new epidemic prevention awning

2.2. The top surface parts

In terms of awning materials, the material for folding awning includes monocrystalline silicon solar panels, pressure power generation board, folding film, and heat insulation layer. Meanwhile, the structure is arranged up and down with upper pressure power generation board and lower solar power generation board. To ensure that the canopy surface will not be damaged in the process of folding and opening for many times, folding film is pressed on both sides of the splicing board in the design. To keep the canopy cool and comfortable, the interior of the canopy is insulated. In addition, the splicing position is designed to have a certain gap to ensure the folding. There are also a few gaps between the upper and lower panels, which are conform to the folding structure. This combination design can meet the needs of realizing the folding function, when expose to energy input in various environmental conditions and weather. A 50*200cm pressure generator board is placed on the side near the door at the bottom of the quarantine cover, which fully considers as a space for human activities, and to collect piezoelectric energy as much as possible while saving piezoelectric materials.

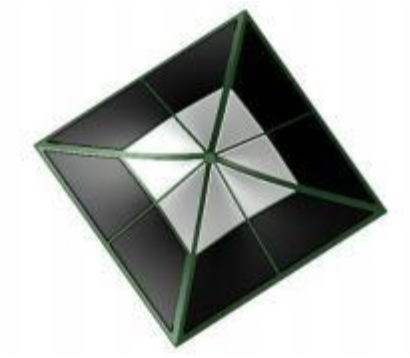

Figure 2. Schematic diagram of solar panel generator board

Figure 3. Schematic diagram of pressure

3. Circuit

The design uses self-powered energy technology, don't need to charge, but only rely on their own energy from outside and timely storage. Supercapacitors usually have high power density and long cycle stability, which are very suitable for application in energy storage components of self-powered energy systems [5]. On the one hand, high power density is very suitable for bearing large output current, while good cycle stability is suitable for improving the service life of self-powered energy systems. System control adopts STM32F103C8T6 as the master chip with abundant external expansion functions [6]. Therefore, a set of self-powered energy system with solar panel and pressure generator board as the energy input, super capacitor (specification 8F/5V) as the energy storage element, and STM32 microcontroller as the core of the control circuit is designed.

3.1. Collecting circuit

In this design, the power source stored by the supercapacitor is divided into two parts, which are solar panel power generation and piezoelectric material power generation. Solar panel power generation is dependences on the intensity of sunlight exposure; therefore, the output voltage of the solar panel will fluctuate. It is important to stabilize the voltage to 5V before charging the supercapacitor. The voltage regulator circuit adopts XL6009 automatic voltage rise and fall module, R2, R1, and XL6009 chip internal circuit composed of negative feedback stable output voltage by the resistance R2 and R1 control voltage amplification, and the output voltage (VOUT) calculation formula is = 1.25* (1+R2/R1), in which the efficiency can reach more than 90%.

Figure 4 shows the schematic diagram of the pressure generator board. Pressure plate power generation: Due to the variability of wind and rain in the environment and the randomness of the force in the process of walking, the pressure of piezoelectric ceramics is different, thereby the voltage of the output of piezoelectric ceramics will be unstable, which may produce alternating current. The full-bridge corrector is used to rectify the unstable AC in the transmission circuit of the pressure plate, subsequently the voltage is raised to 5V through the booster module to enter the storage of the supercapacitor component. Boost module adopts SX1308 chip, input wide voltage 2V-24V, working frequency is fixed to 1.2mhz, internal 4A current limit, output voltage up to 28V, and maximum efficiency up to 97%.

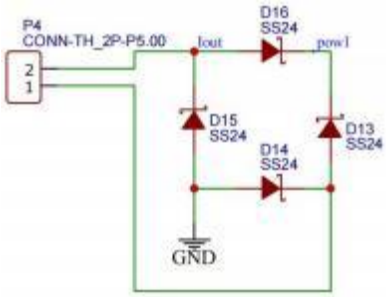

Figure 4. Schematic diagram of pressure generator board

3.2. Discharge circuit

The discharged circuit in this design is mainly the circuit of the supercapacitor. The discharged output voltage of the supercapacitor is 5V, and the input voltage of the STM32 mono-chip computer is selected to 3.3V, thereby it needs to go through a voltage regulator circuit to reduce the voltage from 5V to 3.3V, and input 48 pins of the STM32 mono-chip computer. The voltage regulator circuit uses Low Drop-out Linear Regulator (LDO). VOUT is connected to the reverse and forward ends of the LDO error amplifier through two resistor dividers. Metal-Oxide-Semiconductor Field-Effect Transistor (MOS) drive is used to adjust the output voltage to achieve output stability. When the output voltage increases, the amplifier output voltage increases, the G-pole voltage of the PMOS tube increases with decrease in Undoped Silicate Glass (USG), and the output current and voltage of positive channel Metal-Oxide-Semiconductor (PMOS) is smaller forming a negative feedback system.

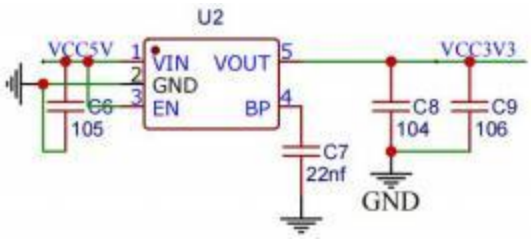

Figure 5. Voltage regulator circuit diagram

3.3. Part of the electrical output circuit

The anti-epidemic tent is connected to each pin of STM32 MCU to achieve different functional control effects. The display control circuit consists of STM32 MCU which has an internal LTDC LCD controller, and using some parts of CDRAM space as video memory which can directly control the LCD panel, therefore another LCD controller chip is not required. **Figure 5** shows the voltage regulator circuit diagram. The STM32's LTDC LCD controller supports up to 800x600 resolution screens that display the time, temperature, and pressure values in real-time.

Lighting device driving circuit: The use of electromagnetic relay on low voltage and weak current control circuit to control high voltage and strong current working circuit, the output circuit of the electromagnetic relay, and lighting device connection. Set pin PC13 of STM32 as the corresponding pin of output mode, connect pin PC13 with the 3.3V voltage output port, and connect to the input loop of the electromagnetic relay as power supply. The level of the pin can be fixed by Supply Chain Management (SCM) program to control the output circuit of the electromagnetic relay, to control the working state of lighting devices. Lighting devices have two modes of operation, key mode, and automatic mode. The key

mode is connected with the key circuit by the switch, and the switch can be used to manually control the connected state. Meanwhile, automatic mode is to achieve intelligent lighting through A/D conversion module, SCM can detect whether the pressure power generation device is generating power, also can detect the resistance value of photosensitive resistance.

4. Energy saving performance calculations

The epidemic prevention canopy that we designed is 300cm long, 300cm wide, 200cm high, and 295cm high. The specifications of single solar panel are 560mm*540mm monocrystalline silicon solar panel with 60W power and 12V output voltage.24 solar panels are installed on the roof of the epidemic prevention canopy. Taking Wuhan as an example, the average sunshine time in Wuhan is about 1950h a year, thereby the average sunshine time is 5.3h a day. The calculated DC power output of solar panels is the nominal power of solar panels. Solar panels in field operation often fail to meet the standard test conditions, and the allowable deviation of output is 5%. Therefore, the influence coefficient of 0.9 to 5% should be taken into account when analyzing the output power of solar panels. The photovoltaic panels on the top of an epidemic prevention canopy generate 2.014kWh of electricity per day.

At the bottom of the roof, a pressure generator plate of 50*200cm size is used, with a single specification of 50*50mm. Considering that there should be a certain gap between the pressure generator plates in parallel, and according to the human foot type and the force distribution characteristics when contacting the ground, the piezoelectric plates are arranged, a total of 345 pieces is calculated. In the range of elastic deformation, the weight of a human is 60kg, the acceleration of human foot is 10m/s2, the piezoelectric constant is D = 1010×10- 12, the relative dielectric constant is ε=4450, the density is ρ=7.39ε×103kg/m3 are calculated based on a stepping piece of piezoelectric ceramic which can generate 0.175MW electric energy. At the bottom of the canopy, 345 piezoelectric ceramic pieces are installed, which can generate 60.4MW electric energy at a time. Taking the comprehensive nucleic acid test of a university as an example, 25 epidemic prevention awnings were set up for more than 25,000 people in a university, and all of them were required to complete the test within 6 hours. One person took about 7 steps in and out of the epidemic prevention awning, and each step was covered with 3 pressure generating boards on average. Therefore, the energy generated under an epidemic prevention awning in a nucleic acid test was 1.205kWh.

The roof is equipped with a pressure generator board which can input energy irregularly from environmental wind and rain. The diameter of a raindrop ranges from 1 to 6mm. According to the raindrop spectrum, the total density of raindrops is 3000-10000/m3, the rain time is 5 hours, the rainfall intensity is 0.97-1.95mm/min, and the wind speed is 8.0-10.7A. A quarantine canopy can provide 0.415kWh of electricity per day. In the context of epidemic prevention and control, a new epidemic prevention awning can generate 3.219kWh of power on sunny days, and the solar power panel can generate 2.023kWh of power on rainy days, in which only about 20% is generated on sunny days. Taking Wuhan Institute of Technology Liufang Campus as an example, the campus has nearly 30 epidemic prevention tents, including 7 temperature tents that need electricity and work for 24h a day. The temperature measuring tent is equipped with an electric fan to ensure the air flow in the tent, and a light and a screen to display the temperature of the students. The temperature tent is equipped with Opple Lighting Co., Ltd.'s energy-saving lamp with power usage about 18W. It is usually turned on at 18:00 in the evening and turned off at 6:00 the next day. It works for about 12h a day. The electric fan fixed in the temperature measuring tent is a circulating fan with a power of 31W with low noise. The electric fan is turned on in hot weather (used all day), and the use time accounts for about one quarter of the whole year, namely 3 months. The established temperature measuring instrument is used all day and the power is about 20W. In a year, the temperature measuring tent in school includes three months with fans usage and nine months without fans usage. When fans are used,

the average power consumption of a day is 1.44kWh, while when the fan is not used, the average power consumption of a day is 0.696kWh, and the effect of self-supply can be achieved in all weather conditions. An epidemic prevention tent consumes about 322.488kWh of electricity in a year. At present, China consumes about 0.34kg of coal for one hour of electricity generated, and 0.87kg of carbon dioxide is generated based on 70% carbon content of coal. By using the new epidemic prevention tent, we can reduce coal consumption to 767.52kg per year, subsequently reduce 1.96tons of carbon dioxide emissions. The effect of energy saving and emission reduction is obvious.

5. Working principle and performance analysis

The anti-epidemic tent consists of a steel frame canopy, a compressible pillar structure, and an anti-epidemic covered with solar and pressure panels. The design of power planning and circuit control to STM32 microcontroller are the core, supercapacitor as the storage element with the corresponding functional modules to achieve.

On sunny days, when the sun shines on the anti-epidemic tent, the solar energy is converted into electric energy and stored in the supercapacitor through photovoltaic power generation panels, and the output electricity is applied to various functions in the shed. In windy and rainy weather, the power of wind and water is converted into electric energy by the pressure generator board and stored in the supercapacitor or provide electric energy for various activities in the canopy. When entering or leaving the anti-epidemic tent, people step on the pressure of the power plate, piezoelectric material connected to the circuit and disinfection equipment which supplies the power that they need.

Various details of the design allow users to operate with a high degree of convenience and comfort. When the voltage is detected in the pressure generation device and the photoresistor resistance value is smaller, meaning that the light is dim and someone is passing through. At this time, the MCU controls the output loop of the electromagnetic relay to make the lighting device work. The above mentioned two kinds of electrical function control circuits applied in the new epidemic prevention canopy can well collect and store energy and output it for people's convenience, to achieve the effect of energy saving, emission reduction, and green environmental protection.

6. Conclusion

To a certain extent, this design solves the problems of poor stability, incomplete power supply function, difficult to cope with harsh environment power supply, and single function. The pillar structure ensures the simple handling of the epidemic prevention canopy, and also ensures the stability and safety of the epidemic prevention canopy.

At the same time, power supply can provide the epidemic prevention canopy more functions, improve the utilization rate, and environmental protection of the epidemic prevention canopy. In addition, this design combines small supercapacitors and multi-functional tents with high efficiency of photovoltaic and piezoelectric materials, and at the same time, a set of self-supplied energy system is designed. In response to the current situation of epidemic prevention and control across the country, the concept of combining small supercapacitors, photovoltaic, and piezoelectric materials has been creatively adopted, and a variety of energy storage and conversion methods have been used to save energy and to reduce corresponding pollution emissions.

Disclosure statement

The authors declare no conflict of interest.

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Flood Risk Forecasting and Early Warning Technology for Medium and Small Rivers in the Yellow River Basin Induced by Heavy Rain

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Abstract: The Yellow River Basin is one of the important sand-producing and sediment-transporting areas in China, and one of the three most important sand-producing areas in the world. The amount of sand and dust days in the "Three Norths" (Dongbei, Xibei, and Huabei) area has increased, and regional sand and dust storms have occurred frequently. There are generally more serious hidden danger points of debris flow geological disasters in small and medium-sized river basins. The technical achievements of flood risk forecasting and early warning for medium and small rivers in the Yellow River Basin based on rainstorm-induced floods are important technical supports for flood forecasting and early warning for medium and small rivers. Based on this, a case study was carried out on the problems such as the weak forecasting and early warning ability of flood disasters induced by heavy rain and the low accuracy of flood disaster loss assessment in the flood disasters of medium and small rivers, for the reference of relevant personnel.

Keywords: Rainstorm; Yellow River; Flood; Risk warning

Online publication: October 26, 2022

1. Introduction

The Yellow River Basin is the largest inland river basin in China and the most important water source conservation area in arid and semi-arid regions of China. Since 1998, with climate change and population growth, China has experienced frequent rainstorms and floods. According to statistics, by the end of 2018, there were 4,164 small and medium-sized rivers in the country, accounting for about 66% of the total number of rivers in the country. Among them, the losses from rainstorms and floods accounted for more than 77% of the national losses from floods, and the average annual losses from floods reached 12.69 billion yuan. Especially since 2019, torrential rains and floods have affected 246 million people in 31 provinces (autonomous regions and municipalities) across the country, with 13.82 million dead and missing. Heavy rains and floods caused huge losses. In order to accurately analyze the flood disaster risk points of medium and small rivers, reduce flood losses, and ensure the safety of people's lives and property, it is urgent to explore and improve the flood risk forecast and early warning technology system for medium and small rivers [1-10].

2. Research background

Floods in the upper Yellow River generally occur from May to September, especially from July to

September 2019. When a flood occurs in the upper reaches of the Yellow River, the flood process and the flood peak stage are located at different river sections. Torrential rain is the main factor for the appearance of the flood peak, and may be accompanied by secondary disasters such as mountain torrents and debris flows caused by strong precipitation. Small river floods in the basin are typical flood disasters. Because the flood of small and medium rivers is a special phenomenon of water engineering disasters, it affects the safety of water for social and economic life and social stability. Through in-depth analysis and research on the flood events of small and medium-sized rivers in the Yellow River Basin induced by heavy rain from July to September 2019, it is found that there are two main stages in the rainfall process that affect the floods of small and medium-sized rivers: one is that during the rainstorm-induced period, the Yellow River Basin flows into the Yellow River banks in the middle reaches of the Yellow River and induces large floods; the other is that during the rainstorm-induced period, the Yellow River Basin enters the middle and lower reaches of the Yellow River and causes large floods.

3. Simulation and prediction of hydrological situation in the Yellow River Basin

According to the climatic characteristics of the Yellow River Basin, combined with the previous rainstorm and flood monitoring data and the flood experience value of the regional rainstorm and flood forecast model, combined with the precipitation characteristics of different periods in the rainfall process and the hydrological situation prediction results of the small- and medium-sized river basins, the flood risk simulation and prediction were carried out. The rainfall in the Yellow River Basin generally presents two trends: one is that the rainfall is concentrated in time and space, and the precipitation presents a "light raindrop" distribution; the other is that the rainfall in the basin presents a "moderate raindrop" distribution. Among them, the precipitation in the flood season in the upper reaches shows a distribution of "moderate raindrops," and the rainfall is 149–265 mm; the precipitation in the middle reaches shows a distribution of "light raindrops" in the flood season, and the rainfall is 610–1245 mm; the rainfall in the lower reaches of 1830–2100 mm showed "moderate" to "heavy raindrops". The research shows that: the precipitation in the Yellow River Basin in the summers present the characteristics of first concentration and then dispersion; the rainfall in the flood season is moderately high; the total annual precipitation presents a "light raindrops" distribution. Torrential floods are characterized by distinct time periods and strong intensity. Among them, January to March is the period with the highest precipitation in the Yellow River Basin; June to August presents characteristics of moderate and light rain areas due to many factors; from September to October, there are distinct characteristics of moderate rain; while October to November is the period of heavy rain. Combined with historical data analysis and trend forecast characteristics, it can be seen that the precipitation in the basin in three months is 3.5 times that of the precipitation in 1951-2007, and the precipitation in the next 2-3 years is predicted to increase annually.

3.1. The characteristics of "light raindrops" in the Yellow River Basin

"Light rain" refers to the amount of rainfall that occurs on average in a certain period of time. According to the characteristics of meteorological elements of "light raindrops" and the characteristics of heavy rain and flood patterns in different areas of the basin, forecast and early warning analysis of light raindrop values are carried out. The research shows that the annual rainfall in the basin is 610–1245 mm in moderate and light rain areas, and the precipitation is characterized by dispersion. Among them, the area with the highest frequency of "light raindrops" is Yanchuan County, whose monthly average rainfall was 541 mm on June 6; the daily average rainfall of "Changning County" appeared on July 8, which appeared between June 13 and July 7, and the average monthly rainfall is 544 mm. The rainfall in the "light rain area" is concentrated between July and August, and its monthly precipitation generally exceeds 500 mm. Although the "Middle Yellow River Area" has obvious precipitation process, its precipitation is not high. Among them, the

monthly precipitation of Yanchuan County is 829 mm, which is the county city with the 6th highest rainfall in China. The monthly precipitation at Sanmenxia and the Yellow Committee station both reached 640 mm or more, ranking the top three stations in the Yellow Committee in recent years; and Yan'an station reached more than 833 mm.

3.2. Historical and hydrological overview of rainstorm and flood

According to the hydrological and meteorological observation data and the evolution characteristics of the hydrological situation of the regional rainstorm and flood forecasting model, we could carry out the rainstorm and flood risk forecasting work for medium and small rivers in the basin, and discuss the flood risk forecasting and early warning technology for medium and small rivers in the Yellow River Basin, so as to provide theoretical basis for the flood risk prediction and early warning of small and medium-sized rivers in the Yellow River basin. (i) The general overview of the Yellow River Basin and historical data statistics show that the regional distribution of the basin basically presents a spatial distribution pattern of high in the west and low in the east. Heavy precipitation is concentrated in the eastern mountainous area, and rainfall in the central and northern areas is relatively small. There is more precipitation in the central and northern regions, and less precipitation in the central and southern regions; less precipitation in the south, and more rain in the north, ranging from heavy rain to heavy rain. Because the precipitation in the upper reaches of the middle and small rivers in the region is significantly more than that in the middle reaches, the precipitation in the middle reaches is significantly less. (ii) According to the analysis results of flood characteristics in the Yellow River Basin, there were 3 types of rainstorms and floods in the basin from 1951 to 2007: 4 times were in the upper reaches, 4 times were in the middle reaches, and 2 times were in the middle reaches. Besides, there were also 2 rainstorm and flood disasters, and 1 rainstorm and flood disaster occurred in the downstream during the same period.

3.3. Monitoring and early warning of water and rain conditions in medium and small rivers

Based on the actual situation of precipitation during the flood season in the Yellow River Basin, the characteristics of flow evolution and the hydrological situation of medium and small rivers, using the hydrological monitoring stations and channel scale sections of medium and small rivers in the Yellow River Basin, a forecasting and early warning method for hydrological elements such as continuous observation and automatic monitoring of hydrological elements is established. The monitoring of hydrological elements refers to the analysis of the hydrological elements and their movement laws formed by natural or human factors from a physical point of view, the investigation and monitoring of the changes of hydrological elements, the monitoring of time series and the analysis of characteristic changes, which involves three aspects: physics, chemistry, and climatology. This method requires long-term tracking observation of hydrological elements and compared to meteorological observations, and involves the use of time series. The main research objects of river runoff forecasting and forecasting technology are the continuous observation data of river runoff, the artificial monitoring stations within the river basin, and the automatic monitoring of river flood data. Combined with the current status of water resources in the Yellow River Basin and the development trend of future hydrological elements, the existing continuous observation data of hydrological elements and meteorological observation data were incorporated into the water and rainfall monitoring, forecasting and early warning system for small and medium rivers in the Yellow River Basin for monitoring and early warning technology research.

4. Flood risk of medium and small rivers induced by heavy rain

Small- and medium-sized rivers are important carriers of flood occurrence and spread, and have high flood disaster risks. The flood risk induced by heavy rain is an important factor affecting the flood forecasting

and early warning ability of medium and small rivers, both globally and locally. According to the statistics of the International Hydrological Organization (ICRA), geological disasters such as landslides and debris flows caused by rainstorms account for 46% of the total impact of flood disasters worldwide; 30% of the total impact of flood disasters are caused by rainstorms in China. The high frequency, suddenness, and wide influence of heavy rain in small and medium-sized river basins is an important cause of heavy rain and flood disasters. At present, the accuracy flood disaster prediction in small and medium-sized rivers at home and abroad is generally low, and it is difficult to predict the losses of flood disasters. In recent years, some advanced achievements in flood forecasting and early warning of small and medium-sized rivers have emerged one after another. For example, there was a flood disaster on July 7, 2013, at the main stream of the Yellow River in Shaanxi Province; the Longyangxia Hydrological Station in the Bailong River Basin of Shenmu City, Yan'an City, Shaanxi Province performed an assessment on the damage caused by rainstorm flood disaster on July 16, 2014, which turned out to be 5.3–9.3 m/s. In addition, since 2013, there have been many floods in the upper reaches of the Yellow River where the peak discharge is greater than the design standard [11]. Therefore, it is foreseeable that in the future, the risk prediction and early warning of flood disasters in medium and small rivers in the Yellow River Basin will become the key technical research direction of rainstorm flood disaster loss assessment and early warning.

4.1. Spatial features

Focusing on the key technical problems of flood disaster risk forecasting and early warning in small and medium-sized rivers in the Yellow River Basin, according to historical data, 4 national-level hydrometeorological stations monitors the situation of the basin within 24 hours after the occurrence of heavy rain, and showed that a heavy rain and flood disaster event occurs every 4 hours [12-14]. During the heavy rainfall period, the probability of flood disaster events with flood peak flow greater than the design standard at each station is greater than 10% [15], which means that there is a probability of a major flood every 5 days. During the heavy rainfall period, the frequency of heavy rain and floods reached 66.5%, and the flood risk level reached Level II or Level III. The frequent occurrence of flood risk events induced by heavy rainfall is mainly due to changes in the control conditions of precipitation and runoff in the basins of small and medium-sized rivers. Rainstorm and flood disasters often cause abnormal changes in river runoff in the river basin, increase discharge flow from upstream reservoirs, and accelerate or decrease the rise of water levels in some river basins. According to the analysis and statistics of the national flood risk level monitoring data of medium and small rivers from 2013 to 2017 by the Monitoring Information Center of the Ministry of Water Resources, the cumulative number of floods in medium and small rivers in flood seasons with a flood risk level of 4 or above from 2014 to 2017 was 777, 488, and 444 times, closely related to the flood risk level during the occurrence of heavy rain and flood disasters.

4.2. Key parameters

The main factors affecting the loss of flood disasters in small and medium-sized rivers include flood intensity, rainfall, and duration of rainstorm. For example, the intensity and duration of rainstorm have a direct impact on flood loss, but its changing trend is uncertain. It is reflected in the peak flow and rainfall. At present, the intensity of rainstorm and the number of rainy days is generally used in the Yellow River Basin to carry out real-time forecasting and early warning of peak flow and rainfall. At the same time, the flood intensity parameter also directly affects the peak flow and contributes to the number of flood days [16]. Flood intensity parameters mainly include indicators such as within 1 day and within 24 days, and the number of flood days needs to be comprehensively considered according to the actual situation of the Yellow River Basin. The number of flood days is mainly formed by the influence of upstream water and downstream rainfall. Usually, the number of flood days varies from 1 day to 24 days, but the rainfall at

different precipitation stations shows different trends. For the number of flood days within 2 days, it is necessary to use relevant formulas to calculate and generate simulated flood peak flow series and flood daily rate series according to the characteristics of each site.

5. Case studies

5.1. Case description

From June to July 2018, large regional rainstorms and floods occurred in most of the Yellow River Basin. Among them, a total of 8 large-area heavy rainfall processes occurred in the Loess Plateau in the middle reaches of the Yellow River, and 7 of the processes had a rainfall exceeding 100 mm. The eight heavy precipitation processes in Shaanxi Province are from 8:00 am on July 9 to 8:00 am on July 11, from 8:00 am on July 12 to 8:00 am on July 13, from 8:00 am on July 13 to 8:00 am on July 14, from 8:00 am on July 14 to 8:00 on July 15, and from 8:00 am on July 15 to 8:00 am on July 17. On July 21, 2019 to 8:00 am on July 14, 2020, a total of 5 floods occurred in small and medium rivers (involving 2 in Shaanxi Province [Bailong River, Xidahe] and 1 in Gansu Province), resulting in 14 deaths, 149 people were missing, 247 households were affected, the affected area of crops was 148.4km^2 /d, the affected area of crops was 86.7km^2/d, and the economic loss was 8.675 billion yuan. Two major floods occurred in Bailong River and Xidahe respectively (causing 2 deaths). This is a report after the dam failure that occurred on August 16, 2019, when the Bailong River flow exceeded 1000 m/s. According to the analysis of flood impact, the flood has the characteristics of hysteresis. This indicates that there will be greater risks and hidden dangers for the floods of medium and small rivers in the Yellow River Basin.

5.2. Summary of results

A technical system for assessing and simulating the flood risk of small- and medium-sized rivers was constructed in the basin from the site, time and space scales, and issuing flood early warning and impact assessment in advance, which realizes the real-time and accurate flood risk forecast and early warning for small and medium-sized rivers. By systematically evaluating and simulating the flood risk of medium and small rivers in the Yellow River Basin induced by heavy rain, the conclusion of flood impact assessment was given. Besides, a flood risk forecast and early warning technology system for medium and small rivers was proposed based on the results of flood risk assessment for medium and small rivers. Flood impact indicators such as flood peak time and water volume were proposed to provide a reference for flood control decision-making in the Yellow River Basin based on the multi-scale numerical simulation results of equal rainfall parameters and water level stations. The results of flood risk assessment provided forecast conclusions such as river water level evolution trend forecast, flood risk forecast factors, flood risk forecast and early warning indicators, and flood risk levels, and provides a reference for the decision-making of flood control and disaster reduction in the Yellow River. In view of the problems of large amount of data and complex data sources faced by flood risk forecasting and early warning of high-flow medium and small rivers, the research on the integration and data fusion of hydrological resources and data resources has been carried out, and a data set based on flood information analysis and hydrological information fusion was constructed to realize data information sharing and data resource integration and application. A flood risk forecast and early warning model and operational service platform for small and medium-sized rivers was established, and a flood risk forecast and early warning system for small and medium-sized rivers with water level as the main factor and small flow as the supplementary factor was constructed, providing technical support for the operational application of flood risk forecast and early warning for small and medium-sized rivers in the Yellow River basin.

5.3. Application results

The research results have been popularized and applied in Inner Mongolia, Ningxia, Shaanxi, Shanxi, Gansu, Qinghai, Ningxia and other places. Among them, 31 hidden danger points of mountain torrent disasters were newly discovered in 2019, an increase of 3 compared with 2018. In 2020, 26 hidden danger points of mountain torrents were newly discovered, an increase of 1 compared to 2018.

6. Conclusion

Mountain torrents are a major threat to the safety of people's lives and property in the Yellow River Basin. In recent years, the intensity of rainstorms in the upper reaches of the Yellow River has gradually increased, and mountain torrents and floods in small and medium-sized rivers are prone to frequent occurrences. Through the establishment of flood risk forecast and early warning system for small and medium-sized rivers, the risk warning and service can be provided to the downstream people from the beginning to the end of the flood. At the same time, through the mountain torrent risk early warning signal release platform and the flood forecast and early warning products based on business calculation results, it provides an effective basis for flood defense, and greatly reduces the probability of mountain flood disasters or secondary disasters caused by untimely forecasts.

Disclosure statement

The authors declare no conflict of interest.

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Practice and Exploration of Mixed Teaching of Microelectronics

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Abstract: The mixed teaching mode plays an increasingly important role in stimulating students' interest and autonomy in learning, and strengthening students' learning ability. The full integration of mixed teaching mode and microelectronics teaching can not only achieve the teaching objectives smoothly, but also enable students to deepen their understanding and memory of relevant knowledge with the help of diversified and interesting teaching methods. Therefore, this paper takes the microelectronics course as an example to practice and explore the effective ways to carry out the mixed teaching mode. Teachers should not make full use of online and offline teaching resources, but also actively improve the traditional assessment systems. Through the continuous improvement of the practicality of online and offline teaching content, an easy-to-complex teaching method with a coherent content structure can be adopted to stimulate students' learning motivation, improve their enthusiasm for participation, and lay a solid foundation for further improvements in the teaching of microelectronics technology.

Keywords: Microelectronic technology; Mixed teaching; Learning needs; Learning enthusiasm; Learning motivation

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1. Introduction

The mixed teaching mode takes online teaching and offline teaching as the channel, fully integrates the advantages of traditional online teaching and classroom teaching, and is an effective teaching mode that meets the cognitive needs of students. The full integration of online teaching and offline teaching mode can completely eliminate the constraints on time and space that traditional students are subjected to when learning in classrooms, and ensure that students can master specific knowledge from simple to in-depth based on the teaching content designed by teachers. Microelectronics is a complex course as it involves theoretical, practical, technical, engineering, and other diversified characteristics, and plays an important role in promoting students' ability to apply microelectronics knowledge. Therefore, teachers should first thoroughly change their traditional spoon-feeding style teaching, actively develop online and offline teaching resources, take scientific measures to promote the full integration of the two, and ensure that students can fully absorb the content of online and offline teaching resources under their guidance. In order to optimize time management, preview and review can be done before class and after class and use class time to solve problems and answer questions.

2. Enrich the online and offline teaching resources to fully meet students' learning needs

To ensure the smooth development of microelectronics teaching, teachers should attach great importance to the richness of teaching resources and create a good environment to fully utilize various teaching

materials. In the process of preparing teaching resources for students, the relevant content should not only involve textbooks, cases, films and television programs, pictures, courseware, but also include infrastructure, education, teachers and other resources. In a broad sense, it also involves educational policies. In the process of integrating teaching resources, teachers should ensure that relevant elements are highly vivid, visually appealing and intuitive, so that students' learning needs can be fully met. In the process of microelectronics teaching, online resources mainly include quick lessons in point form, fishbone diagram, pre-class test questions, circuit making, interactive operation, simulations, video learning, original picture, Computer-Aided Design (CAD) operation, video production, demonstration videos, online work and tests, learning guidance map, and many other contents. It can be seen that the construction process of online resources has long-term characteristics [1].

In order to ensure rapid and effective completion of online teaching resource construction, teachers can use the quick lesson function of the teaching platform and video recording mode to make micro lessons for students in combination with classroom teaching. After teaching, teachers can also compile the excellent assignments handed in by students into one video, which will be played before the next class. This can not only help students to refresh their knowledge of the last lesson, but also effectively improve their self-confidence and sense of achievement, and concentrate better during the lessons. Teachers can also upload the prepared online teaching resources to the students' mobile devices through QQ, WeChat, Dingtalk and other platforms, use each module of the teaching platform to establish a microelectronic course with complete and coherent structure for the students. The contents of the course can then be uploaded in order according the designed course structure.

In the teaching platform, students can not only watch quick lessons, courseware, videos and other contents repeatedly according to their needs, but also carry out online test after learning, submit the completed homework to teachers, and discuss the problems with teachers. Teachers can use the teaching platform to upload materials for students, enable students to sign in online, issue notices, help students solve problems, mark the assignments handed in by students, keep up with the students' learning progress, and take targeted measures to encourage independent learning.

Offline teaching resources mainly include lesson outline, props, and printed textbooks [2].

3. Reasonably design online and offline teaching activities to ensure that students' learning enthusiasm is fully mobilized

The first stage is the information release stage. Before the lessons, teachers can upload carefully prepared teaching resources and establish new teaching modules on the teaching platforms. In this module, students will only be exposed to a large number of learning resources, teachers can also release supplementary teaching resources for students in a timely manner based on the actual situation of students, supervise students in completing online previews, guide students in understanding the lessons, and the understand the offline resources prepared by the students in advance. After reading and analyzing the resources and information uploaded by teachers, students can fully understand their own learning tasks and objectives, and actively complete the online preview test task designed by teachers [3].

The second stage is the autonomous learning stage. Students click the learning guidance map in the teaching platform to independently complete their learning tasks. In this process, students can watch CAD videos, simulation videos, knowledge points, quick lessons, and take notes. They can also operate the computer or assemble circuits according to the demonstration videos, timely point out the existing problems, and actively communicate with teachers or other students to successfully complete the online autonomous learning tests assigned by teachers. Teachers should provide timely feedback online, provide professional guidance, summarize the common problems existing in the process of students' independent learning by randomly checking their work and strictly evaluating their test assignments, and explain relevant content

using online videos [4].

The third stage is the offline teaching stage. After fully mastering the situation of students' autonomous learning, teachers provide a centralized explanation regarding problems that could not be addressed during online lessons to the classroom. In class explanations, teachers should not only teach students how to analyze the principles and characteristics of key and difficult problems, but also demonstrate the specific operation process. The students' enthusiasm for learning can be fully stimulated through classroom interactions with the teachers. On this basis, classroom tests can be carried out to evaluate their understanding of key and difficult problems. Finally, students can be assigned with highly targeted homework [5].

The final stage is the summary and reflection stage. After teaching, both students and teachers should reflect on the development of the mixed teaching mode. In the process of reflection, students need to modify the circuit designed by themselves, fill in the feedback form in the teaching platform, complete the homework assigned by their teachers, and summarize the problems they have encountered in the learning process and their learning outcomes. Teachers need to summarize and analyze students' feedback forms, carefully correct the content of homework handed in by students, summarize the problems and gains in the teaching process, and make excellent design works and homework into teaching courseware to improve online resources [6].

4. Strengthen the reconstruction of teaching assessment and evaluation system and pay close attention to students' learning motivation

In the teaching of microelectronics technology, the quality of the student's design based on the requirements of the evaluation system directly reflects their attitude towards learning and whether the learning goals are achieved. Teachers should analyze the characteristics of the mixed teaching mode in detail, take diversified measures, promote the effective integration of process evaluation and summary evaluation, and make teaching tests and teaching activities as the basis for progress evaluation, discover the students' strengths and give them active encouragement [7].

In the process of designing the evaluation system, teachers should attach great importance to the students' learning process, objectively evaluate the students' video learning completion level, online homework scores, test results, participation in classroom discussions, level of interaction based on questions and answers, and completion of hands-on operations, and include online and offline scores to form the overall curriculum evaluation score.

For example, tests before, during, and after class account for 15% of the total score; online homework score accounts for 10% of the total score; online teaching and video learning account for 15% of the total score; online interaction account for 5% of the total score; attendance accounts for 10% of the total score; the completion of the simulation circuit accounts for 15% of the total score; CAD design and circuit completion account for 15% of the total score; and the completion of circuit production accounts for 15% of the total score. In this process, the teaching platform can be used to effectively summarize students' academic achievements to ensure that additional calculations and statistics are not needed. The teaching platform can automatically score students' test results, video learning and attendance. Teachers only need to mark students' online homework and offline assessment results [8].

5. Conclusion

In order to maximize the role of mixed teaching mode in the teaching of microelectronics, teachers should not only make online and offline teaching resources more abundant, which can fully meet students' learning needs, but also reasonably design online and offline teaching activities according to students' cognitive needs and interests, so as to stimulate the students' learning enthusiasm. They can also modify the

assessment and evaluation system according to the characteristics the online and offline teaching mode, and always pay attention to the students learning motivation. For simple knowledge points, teachers can provide students with learning resources and learning methods, encourage students to learn independently, and improve students' initiative in learning. For complex contents, teachers can use modern information technology to demonstrate and explain, so as to further improve the effectiveness of the lessons.

Disclosure statement

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Application of Nonlinear Triangular Fuzzy Fault Tree Algorithm in Predicting Lithium Battery Air Transport Accidents

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Abstract: The traditional triangular fuzzy fault tree prediction model adopts the linear approximation method. Therefore, the accident prediction error is large. Based on the analysis of the error sources and the fuzzy set, the precise calculation method of the event at the top of the fault tree is given. By using the numerical calculation software, an accurate calculation method of nonlinear triangular fuzzy accident prediction was adopted to predict lithium battery air transport fire accidents, and the fuzzy importance of the cause event was calculated.

Keywords: Nonlinear triangular fuzzy number; Fault tree; Lithium batteries; Air transport

Online publication: November 29, 2022

1. Introduction

Lithium batteries are classified as Class 9 dangerous goods, namely miscellaneous dangerous goods, when transported by civil aviation. There are dangers in the air transport of lithium batteries, and unsafe incidents, which threaten the safety of air transport, often occur. Therefore, it is of great significance to predict lithium battery air transport accidents for air transport safety. The fault tree analysis method has been widely used in production accident prediction, but when the fault tree analysis method is used to analyze the actual problem, the probability of the basic event of the fault tree is often difficult to determine. Therefore, Tanaka *et al*. [1] introduced fuzzy mathematics into fault tree analysis; they were the first to apply triangular fuzzy mathematics and trapezoidal fuzzy mathematics to calculate the probability of event occurrence at the top of the fault tree. On this basis, the theory of fault tree and fuzzy fault tree has been applied in the transport of dangerous goods by air. Du and Chen [2] have analyzed the causes of accidents in the transport of dangerous goods by air using the fault tree method. Du and Wang [3] have constructed a lithium battery air transport fire fault tree and made a quantitative analysis of the fault tree based on the principle of triangular fuzzy number and the expert scoring method. However, the aforementioned studies generally involve qualitative analyses of the fault tree, making a linear approximation of the result of fuzzy number multiplication in the operation process, which has a large error. In this paper, the nonlinear triangular fuzzy fault tree algorithm is studied and applied to lithium battery air transport accidents to obtain more accurate fuzzy calculation results.

2. Traditional accident prediction model and error analysis

2.1. Definition of triangular fuzzy number

(1) Definition of fuzzy sets

If A represents the mapping from X to [0,1], and X is the theoretical domain, represented by mathematical symbols as $A{:}X \rightarrow [0,1]$, $x \rightarrow A$; then, A is called fuzzy set, and $\mu_a(x)$ is called membership function.

(2) *L-R* type fuzzy function

The definition is as follows:

$$\mu_a(x) = \begin{cases} L(\frac{m-x}{l}) & x < m \\ 1 & x \in [m,n] \\ R(\frac{x-n}{u}) & x > n \end{cases} \tag{1}$$

where L is a monotonically increasing function that satisfies $0 \le L(x) < 1, \lim_{x \to -\infty} L(x) = 0$; R is a monotonically decreasing function that satisfies $0 \le R(x) < 1, \lim_{x \to +\infty} R(x) = 0$; m is the probability corresponding to the membership degree 1 of the left half of the function; n is the probability corresponding to the membership degree 1 of the right half of the function; and $l+u$ represents the degree of blindness.

(3) Triangular fuzzy function

Trigonometric fuzzy function is one of type functions. The trigonometric fuzzy number function curve is shown in **Figure 1**. In **Figure 1**, m represents the core; $l+u$ represents the degree of A's blindness and is denoted as $A = (m-l, m, m+u)$; and Z is a point on the x-axis. Assuming that the membership function curve of the triangular fuzzy number is represented by the area of the graph enclosed by the axis, the area of the graph is divided into two parts by the line perpendicular to the axis.

(4) α-cut of fuzzy sets

Let A be a fuzzy set. For a given $\alpha \in [0,1]$, the definition of α-cut is $A_\alpha = \{x | \mu_a(x) \ge \alpha\}, x \in X$, as where X is the universal set.

2.2. Calculation steps of fuzzy fault tree

(1) Construct the fault tree to determine the minimum cut set or minimum path set.

(2) The probability of occurrence of basic events is expressed by triangular fuzzy number. It can be obtained based on the interval algorithm of triangular fuzzy numbers. If the triangular fuzzy probabilities of q_1 and q_2 of the occurrence probabilities of basic events x_1 and x_2 are expressed as $(m_1 - l_1, m_1, m_1 + u_1)$ and $(m_2 - l_2, m_2, m_2 + u_2)$, then the arithmetic of the triangular fuzzy number is as follows:

$$q_1 + q_2 = ((m_1 - l_1) \pm (m_2 - l_2), m_1 \pm m_2, (m_1 + u_1) \pm (m_2 + u_2)) \tag{2}$$

$$q_1 \times q_2 = ((m_1 - l_1) \times (m_2 - l_2), m_1 \times m_2, (m_1 + u_1) \times (m_2 + u_2)) \tag{3}$$

$$C \times q_2 = (C(m_1 - l_1), Cm_1, C(m_1 + u_1)) \tag{4}$$

(3) Determine the triangular fuzzy probability of the top event. The fuzzy occurrence probability of the top event can be processed by fuzzy logic AND gate and fuzzy logic OR gate. The calculation formula of fuzzy logic AND gate and fuzzy logic OR gate is as follows:

$$q_{AND} = (\prod_{i=1}^{n}(m_i - l_i), \prod_{i=1}^{n} m_i, \prod_{i=1}^{n}(m_i + u_i)) \tag{5}$$

$$q_{OR} = ((1-\prod_{i=1}^{n}(1-(m_i - l_i))), (1-\prod_{i=1}^{n}(1-m_i)), (1-\prod_{i=1}^{n}(1-(m_i + u_i)))) \tag{6}$$

(4) The median method is used to calculate the fuzzy significance of each basic event. In **Figure 1**, the area of the graph enclosed by the membership function curve of the triangular fuzzy function and the *x*-axis is represented by *S*. If there is a point Z on the *x*-axis, a vertical line perpendicular to the *x*-axis is made through the point, and the entire closed area *S* is divided into S_1 and S_2. If $S_1 = S_2$ is satisfied, the point is called the median of triangular fuzzy numbers. The rules for fuzzy significance comparison by using the median of triangular fuzzy numbers are as follows: the fuzzy medians of two triangular fuzzy numbers A_1 and A_2 are Z_1 and Z_2, respectively; if $Z_1 < Z_2$, $A_1 < A_2$; if $Z_1 > Z_2$, $A_1 > A_2$; if $Z_1 = Z_2$, then $A_1 = A_2$. For a fault tree consisting of *n* basic events, the structure function is $\phi(x_1, x_2, ..., x_n)$, and the fuzzy median of the triangular fuzzy numbers is Z; the structure function of the fault tree without the i th basic event is $\phi(x_1, x_2, x_{i-1}, 0, x_{i+1}, ..., x_n)$, with Z_i as the fuzzy median; the expression of fuzzy importance of the i th basic event is as follows:

$$M_i = Z - Z_i \tag{7}$$

2.3. Error analysis

In calculation step (3) of the traditional triangular fuzzy prediction model, the result multiplied by *n* triangular fuzzy number is a new triangular fuzzy number. The membership function curve of the triangular fuzzy number is by the left endpoint of the triangular fuzzy number, the right endpoints and the intermediate point, and its corresponding membership values of the coordinates connected by a straight line. The straight line connects a triangle formed by three points: the left endpoint of triangle fuzzy number, 0; the right endpoint of triangular fuzzy number, 0; and triangle fuzzy number, 1 (**Figure 2**). In calculation step (4) of the fuzzy fault tree, the basic events of the fault tree can be represented by fuzzy numbers, and then the cut set of each fuzzy number is taken. According to the algorithm of the fault tree and the algorithm of the cut set, the result of multiplying A of *n* triangular fuzzy numbers is α-cut to the power of n; When $n > 1$, the line between the two ends and the vertex is a curve. Only when $n = 1$, it is appropriate for the two ends and the vertex to be connected by a straight line. Therefore, it is wrong to connect the left endpoint and vertex of the fuzzy membership degree at the top of the traditional triangular fuzzy fault tree directly with a straight line.

This paper calculates the product of *n* triangular fuzzy numbers based on the α-cut method to accurately calculate the traditional triangular fuzzy probability. Based on the numerical calculation software, the membership function graph of the improved triangular fuzzy number multiplication is drawn to determine the exact fuzzy importance value of each basic event.

3. Nonlinear triangular fuzzy fault tree algorithm

In this section, the product operation of *n* triangular fuzzy numbers is derived based on the α-cut of fuzzy

set.

3.1. α-cut of triangle fuzzy number

For *L-R* type fuzzy numbers, assuming that both *L* and *R* are reversible functions, α-cut can be described as follows:

$$\alpha = L(\frac{m-x}{l}) \Rightarrow \frac{m-x}{l} = L^{-1}(\alpha) \Rightarrow A_\alpha^L = x = m - lL^{-1}(\alpha) \tag{8}$$

$$\alpha = R(\frac{x-m}{u}) \Rightarrow \frac{x-m}{u} = R^{-1}(\alpha) \Rightarrow A_\alpha^R = x = m + uL^{-1}(\alpha) \tag{9}$$

Therefore, α-cut of fuzzy set *A* can be expressed as follows: $A_\alpha = [A_\alpha^L, A_\alpha^R]$ (**Figure 1**).

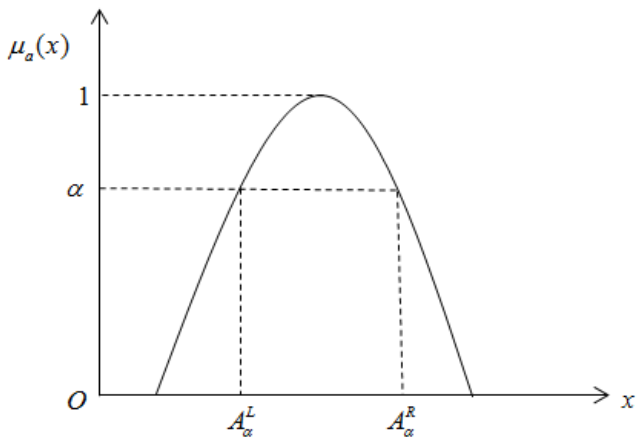

Figure 1. α-cut of *L-R* fuzzy number

For triangular fuzzy number, its α-cut can be represented by the following method. Suppose that $A = [m-l, m, m+u]$ represents a triangular fuzzy number, where A_α represents its α-cut ,

$$\alpha = \frac{x-(m-l)}{l} \Rightarrow A_\alpha^L = x = m - (1-\alpha)l \tag{10}$$

$$\alpha = \frac{m+u-x}{u} \Rightarrow A_\alpha^R = x = m + (1-\alpha)u \tag{11}$$

where, $A_\alpha = [A_\alpha^L, A_\alpha^R]$ denotes the related α-cut , as shown in **Figure 2**.

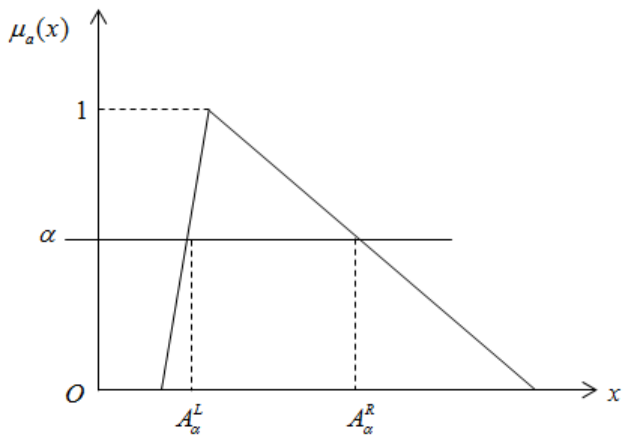

Figure 2. α-cut of triangular fuzzy number

3.2. Fuzzy product operator

Here, α-cut is used to compute the product of fuzzy numbers. The interval $[0,1]$ is divided into n identical subintervals, where each endpoint on the interval is represented as $\alpha_0 = 0$, $\alpha_i = \alpha_{i-1} + \Delta\alpha_i$, $i = 0,1,2,...,n$.

Suppose there are two fuzzy numbers A, B, the relevant α-cut expression is as follows: $A_\alpha = [A_\alpha^L, A_\alpha^R]$, $B_\alpha = [B_\alpha^L, B_\alpha^R]$. The product of α-cut donated as $A_\alpha \times B_\alpha = [L, R]$, where $L = \min(A_\alpha^L B_\alpha^L, A_\alpha^L B_\alpha^R, A_\alpha^R B_\alpha^L, A_\alpha^R B_\alpha^R)$, $R = \max(A_\alpha^L B_\alpha^L, A_\alpha^L B_\alpha^R, A_\alpha^R B_\alpha^L, A_\alpha^R B_\alpha^R)$.

Based on the numerical calculation method, n α_i-cut is calculated. When n is enough, the membership function curve of the product of two fuzzy numbers is obtained.

In the case of N fuzzy numbers, it can be calculated recursively based on the product of two fuzzy numbers. Suppose there are N fuzzy numbers $A_i, i = 1,2,...,N$, the relevant α-cut expression is as follows: $A_\alpha^i = [A_\alpha^{iL}, A_\alpha^{iR}], i = 1,2,...,N$. The α-cut product of A_α^0 and A_α^1 is expressed as $\tilde{A}_\alpha^1 = A_\alpha^0 \times A_\alpha^1 = [\tilde{A}_\alpha^{1L}, \tilde{A}_\alpha^{1R}]$, where

$$\tilde{A}_\alpha^{1L} = \min(A_\alpha^{0L} A_\alpha^{1L}, A_\alpha^{0L} A_\alpha^{1R}, A_\alpha^{0R} A_\alpha^{1L}, A_\alpha^{0R} A_\alpha^{1R}), \quad \tilde{A}_\alpha^{1L} = \max(A_\alpha^{0L} A_\alpha^{1L}, A_\alpha^{0L} A_\alpha^{1R}, A_\alpha^{0R} A_\alpha^{1L}, A_\alpha^{0R} A_\alpha^{1R}). \tag{12}$$

The α-cut product of $\tilde{A}_\alpha^1$ and A_α^2 is $\tilde{A}_\alpha^2 = \tilde{A}_\alpha^1 \times A_\alpha^2 = [\tilde{A}_\alpha^{2L}, \tilde{A}_\alpha^{2R}]$, where

$$\tilde{A}_\alpha^{2L} = \min(\tilde{A}_\alpha^{1L} A_\alpha^{2L}, \tilde{A}_\alpha^{1L} A_\alpha^{2R}, \tilde{A}_\alpha^{1R} A_\alpha^{2L}, \tilde{A}_\alpha^{1R} A_\alpha^{2R}), \quad \tilde{A}_\alpha^{2R} = \max(\tilde{A}_\alpha^{1L} A_\alpha^{2L}, \tilde{A}_\alpha^{1L} A_\alpha^{2R}, \tilde{A}_\alpha^{1R} A_\alpha^{2L}, \tilde{A}_\alpha^{1R} A_\alpha^{2R}). \tag{13}$$

The α-cut product of $\tilde{A}_\alpha^{N-1}$ and A_α^N is $\tilde{A}_\alpha^N = \tilde{A}_\alpha^{N-1} \times A_\alpha^N = [\tilde{A}_\alpha^{NL}, \tilde{A}_\alpha^{NR}]$, where

$$\begin{aligned} \tilde{A}_\alpha^{NL} &= \min(\tilde{A}_\alpha^{(N-1)L} A_\alpha^{NL}, \tilde{A}_\alpha^{(N-1)L} A_\alpha^{NR}, \tilde{A}_\alpha^{(N-1)R} A_\alpha^{NL}, \tilde{A}_\alpha^{(N-1)R} A_\alpha^{NR}), \\ \tilde{A}_\alpha^{NR} &= \max(\tilde{A}_\alpha^{(N-1)L} A_\alpha^{NL}, \tilde{A}_\alpha^{(N-1)L} A_\alpha^{NR}, \tilde{A}_\alpha^{(N-1)R} A_\alpha^{NL}, \tilde{A}_\alpha^{(N-1)R} A_\alpha^{NR}). \end{aligned} \tag{14}$$

4. Application in the safety of lithium battery air transport

With the continuous development of lithium battery and its wide application, there is a surge in demand for lithium battery air transport. However, lithium batteries are dangerous in air transport. When transported by civil aviation, they are classified as Class 9 dangerous goods, namely miscellaneous dangerous goods. Unsafe incidents involving lithium batteries may occur during civil aviation transport and cargo transport,

in which the consequences of these incidents are relatively serious. Although laws and regulations related to the transport of dangerous goods by air have made strict provisions on the transport of lithium batteries, safety risks still exist in actual transport, thus threatening the safety of air transport. From January 23, 2006, to June 1, 2022, the Federal Aviation Administration (FAA) has recorded 380 air transport unsafe incidents involving lithium batteries [4]. As shown in **Table 1**, the major lithium battery air transport events include overheating (heat but no flame), fire explosion (including smoke), melting, *etc*. Among them, fire accidents, such as smoldering, sparking, smoking, burning, and other fire accidents of different degrees, account for 85.79% of all lithium battery accidents, with 326 cases in total.

Table 1. Statistical table of air transport unsafe incidents involving lithium batteries included by the Federal Aviation Administration

Event	Overheating	Fire explosion	Melting	Expansion
Number of events	27	326	12	15
Proportion of events	7.11%	85.79%	3.16%	3.95%

4.1. Fault tree analysis

"Lithium battery air transport fire accident" is selected as the top event of the fault tree [5], and the nonlinear modular fault tree algorithm is adopted to analyze its application (**Figure 3**).

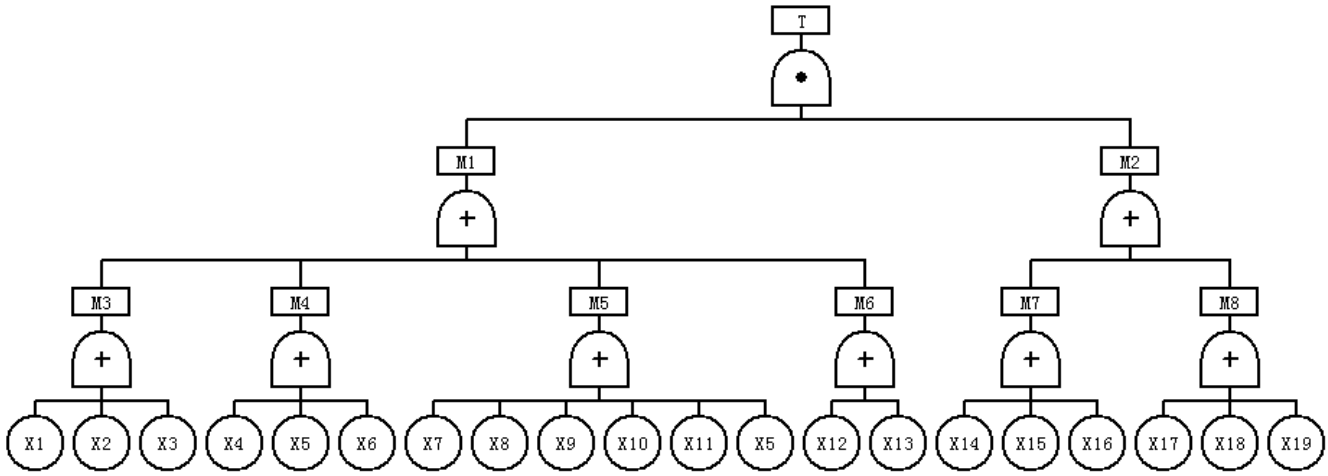

Figure 3. Lithium battery air transport fire fault tree (T, lithium battery air transport fire accident; M1, lithium batteries smoke and catch fire; M2, not in time to save; M3, production quality problem; M4, improper loading and unloading; M5, improper packing; M6, complex transportation environment; M7, not found in time; M8, non-functioning fire extinguishing facilities; X1, design flaw; X2, fake and inferior products; X3, disorganized production quality management; X4, failure to declare or improper declaration, leading to improper loading and unloading; X5, undertrained or untrained personnel; X6, rough handling; X7, improper or no anti-movement measures; X8, improper or no short-circuit prevention measures; X9, improper or no anti-accident measures; X10, packaging container or packaging does not comply with regulations; X11, failure to declare or improper declaration, leading to non-compliance to packaging regulations; X12, the lithium battery reached its maximum pressure or temperature; X13, bump, shock, or impact; X14, crew lacked sufficient information; X15, fire detector or indicator light failure; X16, passengers lack understanding of lithium batteries; X17, unfamiliar with fire extinguishing methods; X18, accidents beyond control; X19, fire extinguisher does not put out fire effectively)

4.2. Median and fuzzy significance calculation

Since there are no accurate records or statistics concerning the probability of occurrence of each basic event

of lithium battery air transport fire accident, the probability of occurrence can be obtained after expert scoring and fuzzy processing of each basic event [6]. Using the nonlinear triangular fuzzy fault tree algorithm and MATLAB programming, the median fuzzy number of the top event Z = 0.35433, as well as the median value and fuzzy importance of each basic event can be obtained (see **Table 2** for specific data). The greater the fuzzy importance of the basic event, the greater the influence on the occurrence of the top event. Otherwise, it indicates that the influence degree of the top event is smaller. The fuzzy importance ranking of each basic event is as follows: $X_4 = X_{11} > X_3 > X_5 > X_{10} > X_{16} > X_6 = X_7 = X_8 = X_9 > X_2 > X_1 = X_{13} > X_{19} > X_{17} > X_{12} = X_{14} = X_{15} = X_{18}$.

Table 2. Basic event fuzzy processing data table

Number	Event name	Event probability	Median fuzzy	Significance
X_1	Design flaw	(0.012, 0.015, 0.012)	0.34529	0.00904
X_2	Fake and inferior products	(0.024, 0.020, 0.024)	0.34268	0.01165
X_3	Disorganized production quality management	(0.029, 0.050, 0.029)	0.32227	0.03206
X_4	Failure to declare or improper declaration, leading to improper loading and unloading	(0.024, 0.060, 0.024)	0.31478	0.03955
X_5	Undertrained or untrained personnel	(0.012, 0.025, 0.012)	0.32242	0.03191
X_6	Rough handling	(0.012, 0.020, 0.012)	0.34195	0.01238
X_7	Improper or no anti-movement measures	(0.012, 0.020, 0.012)	0.34195	0.01238
X_8	Improper or no short-circuit prevention measures	(0.012, 0.020, 0.012)	0.34195	0.01238
X_9	Improper or no anti-accident measures	(0.012, 0.020, 0.012)	0.34195	0.01238
X_{10}	Packaging container or packaging does not comply with regulations	(0.032, 0.035, 0.032)	0.33293	0.0214
X_{11}	Failure to declare or improper declaration, leading to non-compliance to packaging regulations	(0.024, 0.060, 0.024)	0.31478	0.03955
X_{12}	Lithium battery reached its maximum pressure or temperature	(0.002, 0.002, 0.002)	0.35318	0.00115
X_{13}	Bump, shock, or impact	(0.012, 0.015, 0.012)	0.34529	0.00904
X_{14}	Crew lacked sufficient information	(0.002, 0.002, 0.002)	0.35318	0.00115
X_{15}	Fire detector or indicator light failure	(0.002, 0.002, 0.002)	0.35318	0.00115
X_{16}	Passengers lack understanding of lithium batteries	(0.024, 0.030, 0.024)	0.33591	0.01842
X_{17}	Unfamiliar with fire extinguishing method	(0.004, 0.006, 0.004)	0.35071	0.00362
X_{18}	Accidents beyond control	(0.002, 0.002, 0.002)	0.35318	0.00115
X_{19}	Fire extinguisher does not put out fire effectively	(0.022, 0.015, 0.022)	0.34588	0.00845

Basic events X_4, X_{11}, X_3, X_5, X_{10}, and X_{16} have the greatest impact on the occurrence of the top event. These basic events are the most important factors leading to fire accidents in lithium battery air transport. Among them, failure to declare or improper declaration is the key factor. The occurrence of the top event is also influenced by basic events X_6, X_7, X_8, X_9, X_2, X_1, and X_{13}. These basic events have the second impact on the lithium battery air transport fire accidents. The control and management of these risk factors will effectively prevent the occurrence of lithium battery air transport fire accidents. Finally, the probability of occurrence of basic events like lithium battery air transport environment, fire detector or indicator light failure, fire extinguisher failure, insufficient information obtained by the crew, and accidents beyond control is very small, and their impact on lithium battery air transport fire accidents is also relatively small.

5. Conclusion

Based on the analysis of the cut set of each fuzzy number, we find that when the number of any basic event is two or more, the triangular fuzzy membership curve of the top event is nonlinear. As a result, there is a large error in linear prediction using the traditional triangular fuzzy fault tree. The product of triangular fuzzy numbers is calculated by the recursion method and fuzzy set, and the nonlinear membership curve of the triangular fuzzy fault tree top event and the fuzzy importance of each basic event are obtained. The nonlinear triangular fuzzy fault tree prediction algorithm was used in this study to analyze lithium battery air transport fire accidents and calculate the precise fuzzy importance of each basic event.

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Disclosure statement

The authors declare no conflict of interest.

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No author

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Note: When referencing an entry from a dictionary or an encyclopedia with no author there is no requirement to include the source in the reference list. In these cases, only cite the title and year of the source in-text. For an authored dictionary/encyclopedia, treat the source as an authored book.

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As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

1. The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).

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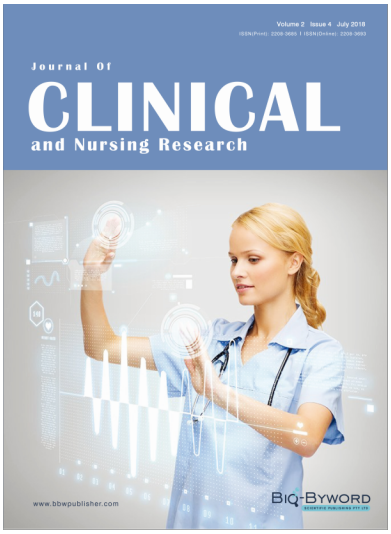

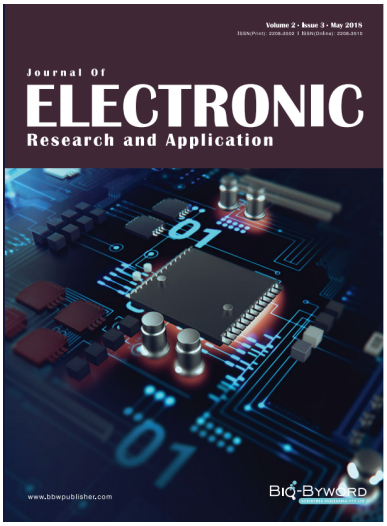

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