Development of a High-Sensitivity Rain and Snow Sensor for LHAASO-WFCTA (Postprint)

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Abstract

The Large High Altitude Air Shower Observatory (LHAASO) is located at Haizi Mountain, Daocheng County, Sichuan Province, at an average altitude of 4,410 m, characterized by a typical alpine mountain climate with rapid weather variations. The Wide Field of view Cherenkov Telescope Array (WFCTA), one of LHAASO's three major observational arrays, requires clear nighttime conditions for operation. To ensure the proper functioning of the telescopes, continuous monitoring of precipitation conditions is essential to guarantee timely shutdown of the WFCTA during rain or snow events. However, due to extremely low temperatures, conventional precipitation sensors cannot operate reliably at the site, necessitating instrument modifications with integrated heating systems. Through laboratory research, a heating device design was completed and subsequently tested in the field. The results demonstrate that the high-sensitivity precipitation sensor can maintain the detection surface temperature above freezing under the site's low-temperature environment, enabling real-time and effective monitoring of precipitation weather, thereby providing critical support for the normal operation of the Wide Field of view Cherenkov Telescope.

Full Text

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Abstract

The Large High Altitude Air Shower Observatory (LHAASO) is located at Haizi Mountain in Daocheng County, Sichuan Province, at an average altitude of 4,410 meters, and experiences a typical alpine mountain climate with rapidly changing weather conditions. The Wide Field of view Cherenkov Telescope Array (WFCTA), one of LHAASO's three major observation arrays, requires operation during clear nights. To ensure normal telescope operation, it is necessary to constantly monitor rain and snow conditions so that WFCTA can be promptly closed during inclement weather. However, due to extremely low temperatures, conventional rain and snow sensors cannot function properly at the site. Therefore, we improved the instrument by adding a heating device. Through laboratory research, we completed the heating device design and conducted field tests at the site. The results demonstrate that the high-sensitivity rain and snow sensor can maintain its detection surface temperature above freezing in the site's low-temperature environment, effectively monitoring rain and snow conditions in real time and providing crucial support for the normal operation of the Wide Field of view Cherenkov Telescope Array.

Keywords: rain and snow monitoring; rain and snow sensor; heating device; LHAASO

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1. Introduction

LHAASO is a national major scientific and technological infrastructure project and the highest-altitude cosmic ray detection facility in the world, primarily composed of the Square Kilometre Array (SKA), the Water Cherenkov Detector Array (WCDA), and the Wide Field of view Cherenkov Telescope Array (WFCTA) [1-4]. The WFCTA contains 18 wide-angle Cherenkov telescopes with a primary scientific goal of precisely measuring the composition and energy spectrum of cosmic rays in the knee region, covering an energy range of 3-30 TeV [5]. Since the wide-angle Cherenkov telescopes contain exposed electronic and optical components [6], they are extremely vulnerable to weather conditions during nighttime operation. Running the telescopes in rain or snow would cause irreversible damage. Therefore, we initially arranged for staff to be on duty around the clock. To improve staff efficiency and enable unmanned operation, we developed high-sensitivity rain and snow sensors and deployed them at various positions around the wide-angle Cherenkov telescopes. These sensors can promptly detect rain and snow signals, enabling real-time monitoring of the telescope working environment and providing feedback to operators to improve decision-making accuracy. This allows timely awareness of weather conditions and telescope shutdown even in unmanned situations.

2. Site Weather Conditions

2.1 Daocheng Weather Analysis

Daocheng is located in southwestern Sichuan Province, on the southeastern edge of the Tibetan Plateau in the central Hengduan Mountains. Situated in a subtropical climate zone with complex plateau terrain and significant elevation differences, the area experiences a plateau monsoon climate. Meteorological parameters obtained from the LHAASO weather station in 2021 are shown in Figure 1. The site experiences predominantly clear weather throughout the year, with abundant rainfall from May to September (Figure 1b). Summer is particularly rainy [7], while other seasons see little precipitation. However, rain and snow often occur at night, posing challenges for nighttime duty personnel. Therefore, high-sensitivity rain and snow sensors are needed to provide timely feedback on precipitation conditions, allowing operators to open or close the telescopes promptly.

The minimum temperature in Daocheng can reach -25°C. During winter, when temperatures are too low, snow does not easily melt into water to trigger the sensor response. Therefore, a heating device must be designed for the rain and snow sensor to ensure efficient and stable operation [7]. Weather data analysis shows that wind speeds are highest from April to June (Figure 1d), reaching up to 13.2 km/h. To ensure stable operation under high wind conditions, the sensor requires a windproof mechanism.

[Figure 1: see original paper] The geographical location of LHAASO (a); monthly rainfall measured by LHAASO Meteorological Station in 2021 (b); monthly temperature measurement at LHAASO Meteorological Station in 2021 (c); monthly wind speed measured by LHAASO Meteorological Station in 2021 (d).

3. Design of Rain and Snow Sensor Heating Device

3.1 Working Principle of Rain and Snow Sensor

The rain and snow sensor operates by using rainwater as a conductor to short-circuit the grating electrodes on the sensor surface, thereby triggering a signal [8]. After conversion, this signal is collected and analyzed by computer programs to determine precipitation conditions. In future work, we will couple the rain and snow sensor to the WFCTA control system. The control flow is shown in Figure 2: the server periodically sends query commands to the sensor via an Ethernet switch, and the sensor responds with corresponding hexadecimal instructions indicating the detection status of multiple sensors. The server then determines whether rain is present based on the returned signal.

To reduce wiring costs and difficulty in the harsh LHAASO environment, we connect the rain and snow sensors to Ethernet switches, which then connect to the server. We use Moxa ioLogik E1210 Ethernet switches, which can directly mirror remote sensor values to local output channels. In addition to the advantages of point-to-point transmission and low wiring costs, we can define Modbus protocols to enhance flexibility. The RS-485 interface we primarily employ offers long transmission distances and strong anti-interference capabilities. The server continuously queries the rain and snow sensors, and if any sensor detects precipitation, it triggers an alarm system. To ensure reliability, the server continues sending query commands even after an alarm is triggered. Coupling the rain and snow sensor to the WFCTA system allows nighttime duty personnel to conveniently and effectively monitor various data points and take appropriate action.

[Figure 2: see original paper] The workflow of rain and snow sensor.

3.2 Design Requirements for Heating Device

Based on site conditions, we identified four key design requirements:

3.2.1 Snow Melting Capability

Since the sensor requires rainwater to short-circuit the grating electrodes, dry snow cannot trigger the sensor. The snow must be melted into water for the sensor to function properly. However, the sensor itself cannot meet this requirement and needs a heating band connected above it. The heating band must also provide some wind protection to prevent snow from being blown away before melting.

3.2.2 Fog and Frost Prevention

Fog and frost that melt into water droplets can also trigger the sensor, causing false positives. Installing a heating band above the sensor can accelerate moisture evaporation, maintain the sensor surface temperature above 0°C, effectively prevent frost formation, and thus avoid false triggering.

3.2.3 Rapid Evaporation

After rain or snow, water may remain attached to the sensor surface even with proper drainage, causing the sensor to continuously report precipitation even in clear weather. The heating band promotes rapid evaporation of residual water and snow when weather clears, ensuring accurate reporting.

3.2.4 Secure Fixation

Since the sensor is placed outdoors where wind speeds can reach 13.2 km/h, the heating device must be securely fixed to the sensor to prevent detachment under any weather conditions.

3.3 Heating Band Dimensions, Shape, and Fixation

To provide wind protection while allowing sufficient precipitation to reach the sensor surface, the heating band is designed as a frustum (truncated cone) shape with a wide top and narrow bottom. To prevent water accumulation that could keep the electrodes short-circuited, a semicircular drainage hole is cut at the bottom of the frustum-shaped heating band. The final heating band parameters are shown in Table 1.

Parameters of band heater: Upper surface diameter = 157.5 mm; Lower surface diameter = 63.5 mm; Vertical height = 57 mm; Drainage diameter angle = 7°.

The rain and snow sensor has uniformly distributed leveling screws at its base. We installed three uniformly distributed iron rings along the lower edge of the frustum-shaped heating band, which are then fixed by pressing them under the screws. This method secures the heating device to the sensor using the sensor's own components, ensuring stable operation under various weather conditions.

[Figure 3: see original paper] Schematic diagram of band heater (a); top view of rain and snow sensor (b).

[Figure 4: see original paper] Complete schematic diagram of the rain and snow sensor (a); picture of the complete structure of the rain and snow sensor (b).

4. Temperature and Power Testing

After completing the initial heating band design, we conducted a series of laboratory tests to select appropriate operating power and temperature settings, verifying whether the design meets actual requirements before conducting field tests in Daocheng's high-altitude extreme environment.

4.1 Heating Band Power Selection

Based on historical temperature data, we first selected a 150 W heating band and fixed it to the rain and snow sensor. Using a constant temperature chamber that can cool to -30°C, we placed the sensor with heating band inside. We set heating temperatures to 40°C, 50°C, and 60°C, and after stabilization, gradually lowered the chamber temperature. Temperature probes monitored the heating band surface and chamber interior temperatures over time. Test results showed that in all preset heating temperature scenarios, the surface temperature could not be maintained above freezing when the environment reached -30°C.

We subsequently tested heating bands with powers of 50 W and 60 W using the same method, finding that neither could maintain stable surface temperatures above 0°C at -30°C ambient temperature. These results indicated that heating bands below 150 W could not enable the rain and snow sensor to work properly in -30°C environments.

Analyzing these results, we estimated that heating bands above 200 W would be required. Considering commercially available options, we tested a 245 W heating band with preset temperatures of 40°C, 50°C, and 60°C. The temperature curves are shown in Figure 5.

[Figure 5: see original paper] The surface temperature of the band heater at different heating powers.

The 245 W heating band successfully heated the surface to 30°C when ambient temperature dropped to -30°C. At this power, snow on the heating band surface melts into water that slides down to the rain and snow sensor surface, achieving the goal of monitoring precipitation.

4.2 Heating Temperature Setting Selection

Through these tests, we selected 245 W as the appropriate power. However, we needed to determine the optimal preset temperature that would melt falling snow without evaporating water too quickly, maintaining high sensitivity. We fixed the 245 W heating band to the sensor and set preset temperatures to 40°C, 50°C, and 60°C. The resulting temperature curves are shown in Figure 6.

[Figure 6: see original paper] Temperature curve of the sensor surface at different preset heating temperatures.

Analysis of data from different preset temperatures shows that at -30°C ambient temperature, the 245 W heating band with a 50°C preset maintains the sensor surface at 3-5°C. This effectively melts falling snow while avoiding false readings from excessive evaporation. Lower temperatures cannot melt snow effectively, while higher temperatures cause water to evaporate too quickly, both leading to monitoring failures.

5. Field Testing at Daocheng Site

After determining the appropriate heating power (245 W) and preset temperature (50°C) through laboratory testing, we conducted field tests at the Daocheng observation base. We fixed the heating band to the rain and snow sensor using the same method and installed the complete assembly at a suitable outdoor location at the LHAASO site. After continuous operation for 24 hours, we obtained the temperature curve shown in Figure 7.

[Figure 7: see original paper] Temperature curve of rain and snow sensors. The red curve shows the sensor surface temperature, and the blue curve shows the ambient temperature.

Under actual weather conditions in Daocheng, the rain and snow sensor with 245 W heating power and 50°C preset temperature achieved surface temperatures reaching 3-5°C. This effectively ensures melting of falling snow while preventing detection failure from excessive evaporation. Comprehensive analysis of field test data confirms that the 245 W, 50°C heating band enables the rain and snow sensor to operate normally under actual site conditions, meeting all requirements for deployment at the observation base.

6. Conclusions and Outlook

The rain and snow sensor converts physical signals into electrical signals. Through long-term testing at Daocheng, it has achieved real-time monitoring of the telescope working environment. In unmanned situations, the sensor can operate normally, improving staff decision-making accuracy and enabling timely closure of Cherenkov telescopes. The heating device designed in this paper can be used in different environments, ensuring the sensor's functionality and reliability while providing timely feedback on precipitation conditions at the observation station.

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Note: Figure translations are in progress. See original paper for figures.