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# The Role of Weather Monitoring Technology in Supporting Islamic Astronomy and Hilal Observation Programs

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**ABSTRACT**

Weather stations are instruments designed to collect and analyze atmospheric data for predicting weather conditions. This literature-based study explores the theories and working principles of weather stations, their main components, and technological advancements through IoT integration. Beyond their importance in agriculture, transportation, and disaster mitigation, weather stations also hold a vital role in Islamic astronomy. Accurate atmospheric monitoring directly influences hilal (crescent moon) visibility studies, rukyat programs, prayer time calculations, and the determination of the Islamic calendar. The findings highlight that innovations in weather station technology not only improve weather predictions but also strengthen the scientific reliability of Islamic astronomical practices, contributing to synchronization between modern meteorology and religious observances.

## I. Introduction

Weather stations have long been essential tools for observing atmospheric changes and providing critical data for meteorological analysis. By measuring parameters such as temperature, humidity, air pressure, rainfall, and wind speed, they contribute to the development of reliable weather forecasting and climate research. In the Islamic context, these atmospheric parameters are deeply connected to ʿIlm al-Falak (Islamic astronomy). The determination of prayer times, Qibla direction, and especially the beginning of the lunar months through hilal observation [1] depends not only on celestial calculations but also on atmospheric conditions. For instance, high humidity, cloud cover, and air pollution significantly affect the visibility of the crescent moon [2]. In this regard, weather stations provide valuable data that can help scholars, observers, and institutions such as the Ministry of Religious Affairs and observatories (like OIF UMSU) prepare more effectively for rukyat al-hilal programs.

However, observational practices today face several challenges. The increasing unpredictability of weather patterns due to climate change often disrupts rukyat activities. Sudden cloud formation, haze from urban pollution, and heavy rainfall in tropical regions like Indonesia make hilal sighting uncertain, even when astronomical calculations show the crescent should be visible [3]. Similarly, during fajr (dawn) observations, atmospheric refraction and local horizon conditions vary greatly depending on air pressure and temperature. Without precise meteorological data, it becomes difficult to distinguish between genuine astronomical light and atmospheric scattering effects.

Another issue is the gap between theoretical prediction and actual field observation. Astronomical models (hisab) may indicate that the hilal is above the horizon and geometrically visible, yet observers often report it unseen due to adverse local atmospheric conditions. This mismatch usually fuels debates in determining the beginning of Ramadan, Shawwal, and Dzulhijjah [4]. Thus, accurate and localized weather tracking instruments are urgently needed to complement astronomical calculations with real-time environmental data.

In recent decades, the integration of weather stations with IoT and real-time monitoring systems has offered new opportunities for Islamic astronomy. Real-time atmospheric data can now be correlated with Hilal observation reports, supporting both empirical observation and hisab. Moreover, observatories such as OIF UMSU have begun to strengthen their programs by combining weather stations with complementary tools such as all-sky cameras, Sky Quality Meters (SQM) [5], CCD-equipped telescopes, and portable meteorological kits. Together, these instruments provide a comprehensive foundation for modern Islamic science observation programs. This study aims to analyze the theory, working principles, and technological developments of weather stations, while highlighting their role in supporting Islamic astronomy, hilal observation, and related research activities. The combination of these tools strengthens observation activities by providing not only astronomical but also environmental and atmospheric context, enabling observers to explain why a hilal was visible or invisible under certain conditions. Furthermore, the integration of IoT-based weather stations offers real-time data transmission, allowing coordination across multiple observation posts and enhancing the reliability of national rukyat programs.

Therefore, the advancement of weather monitoring instruments is not merely a matter of technological sophistication but a practical necessity for Islamic astronomy [6]. By bridging the gap between celestial models and atmospheric reality, these tools ensure that observations of hilal, fajr, and other astronomical phenomena are conducted with greater accuracy, transparency, and scientific accountability.

## II. Method

This study adopts a qualitative approach using the literature review method as its primary framework. The literature review was chosen because it allows for a comprehensive examination of existing theories, technologies, and applications related to weather stations, while also identifying gaps in current knowledge and opportunities for integration into broader scientific and religious contexts. Data were collected from a wide range of credible sources, including scientific journals, academic textbooks, conference proceedings, and relevant online articles that specifically discuss the theory, components, and implementation of weather stations. Emphasis was placed on publications that address both the technological evolution of weather monitoring systems and their applications across various fields. Additionally, sources related to the role of atmospheric monitoring in Islamic astronomy (ʿIlm al-Falak) were considered to connect weather station development with practical needs such as hilal observation, prayer time studies, and Islamic calendar research.

The scope of the review was structured around four key focus areas. First, it analyzes the fundamental theories of weather measurement and the main components of weather stations, ranging from traditional instruments to modern sensor-based devices. Second, it explores technological developments in weather stations, tracing their progression from conventional systems to advanced IoT-based networks capable of real-time monitoring and analysis. Third, it evaluates the roles and benefits of weather stations in multiple sectors, including agriculture, aviation, transportation, disaster mitigation, industry, and Islamic astronomy. Finally, it identifies challenges and potential solutions in the implementation of weather monitoring technology, particularly issues of data security, interoperability, storage, cost, and connectivity. Through this structured approach, the study aims to provide a holistic understanding of weather station technology and highlight its growing relevance not only for general meteorology but also for the advancement of Islamic science observation programs.

## III. Results and Discussion

1. Fundamental Theory and Components of Weather Stations

Weather stations are specialized devices designed to measure and record various meteorological parameters at specific locations. By providing continuous and accurate data, these instruments play a central role in analyzing atmospheric conditions and producing reliable weather predictions. Traditionally, weather observations were conducted manually, but modern developments have introduced automated weather stations equipped with multiple sensors and digital systems that enhance both the efficiency and accuracy of data collection [7].

The most basic and essential element of a weather station is the temperature sensor, which records air temperature, often through a thermistor that responds to changes in electrical resistance. Alongside this, a humidity sensor is employed to measure the amount of moisture in the air, typically using electrolytic or capacitive methods. These two parameters, temperature and humidity, are vital for understanding atmospheric stability, cloud formation, and dew point levels.

Another crucial component is the air pressure sensor, which detects variations in atmospheric pressure by using a sensitive membrane that translates pressure changes into electrical signals. Monitoring air pressure is crucial to forecasting weather changes, as pressure drops often signal the approach of storms or unsettled weather. Similarly, the anemometer provides data on wind speed and direction, using rotating cups or vanes to measure airflow. This information is indispensable not only for aviation and maritime operations, but also for astronomical observations, as wind conditions can significantly impact the clarity and steadiness of the sky [8].

Additionally, a rain gauge is used to collect and quantify precipitation, providing insights into local rainfall intensity and patterns. To ensure that the data collected by all these sensors is not lost, a data logger functions as the central storage and processing unit, organizing the incoming information for analysis. To facilitate real-time monitoring, weather stations are usually supported by a communication system that transmits the recorded data to users or processing centers via the internet or wireless networks. Finally, to maintain uninterrupted operation, especially in remote observation posts, a power supply system is integrated, commonly relying on rechargeable batteries or solar panels.

Taken together, these components form an interconnected system that transforms environmental signals into structured datasets. For Islamic astronomy, this comprehensive set of measurements is particularly significant, as it enables researchers to relate meteorological conditions directly to observational success in activities such as hilal visibility studies, dawn (fajr) light analysis, and long-term lunar calendar research. Thus, the fundamental theory and components of weather stations are not only essential for general meteorology but also for advancing the precision of astronomical observations within the Islamic scientific tradition.

2. Technological Advancements and IoT Integration

Recent technological advancements have transformed the design and function of weather stations, with the most significant innovation being the integration of the Internet of Things (IoT) [9]. This development has revolutionized weather monitoring by allowing real-time data collection, transmission, and analysis across interconnected platforms. IoT-based weather stations utilize advanced digital sensors to measure atmospheric parameters, including temperature, humidity, air pressure, wind speed, and rainfall. The recorded data is automatically transmitted to centralized servers or cloud-based systems, where it can be accessed, analyzed, and shared instantly.

One of the significant advantages of IoT-enabled weather stations is their ability to facilitate remote monitoring. Observers and researchers no longer need to be physically present at the site, as efficient digital communication systems provide direct and real-time access to weather information. This capability has proven particularly useful in critical sectors, including agriculture, aviation, maritime transportation, and disaster management, where rapid decision-making is crucial. Within the context of Islamic astronomy, remote monitoring also enhances rukyat al-hilal activities, as weather conditions across multiple observation posts can be compared and coordinated simultaneously, providing a more comprehensive understanding of atmospheric factors that influence crescent visibility.

Another key advancement lies in operational efficiency. Automated systems reduce the possibility of human error and minimize delays compared to traditional manual observations. It ensures that large amounts of weather data can be gathered with high consistency and accuracy over extended periods. For Islamic astronomy programs, such as dawn (fajr) monitoring or hilal sighting, this precision is crucial because even slight variations in temperature, pressure, or humidity can significantly impact sky transparency and atmospheric refraction.

Furthermore, the integration of artificial intelligence (AI) and machine learning into IoT-based systems allows for the processing of vast meteorological datasets. These technologies can identify subtle climate trends, generate predictive models for extreme weather, and refine visibility forecasts. In the case of hilal observation, AI-driven analysis may one day support predictive models that account for both astronomical and atmospheric variables, bridging the gap between theoretical calculations (hisab) and empirical observations (rukyat).

Looking ahead, future developments in weather monitoring may involve the deployment of drones for atmospheric sampling and remote sky observation, as well as the broader adoption of renewable energy sources to ensure the continuous operation of weather stations in remote or isolated locations. These innovations would not only strengthen general meteorological research but also support observatories such as OIF UMSU, which often conducts hilal and fajr observations in coastal and rural areas where access to reliable power and internet can be limited.

In this way, IoT integration and technological advancements do not simply modernize weather stations; they expand their utility across both scientific and religious domains, reinforcing the role of meteorological data in enhancing the precision and credibility of Islamic astronomical observations.

3. Roles in Various Sectors

Weather stations play a pivotal role across numerous sectors, as they provide critical meteorological data that enables timely and informed decision-making. In agriculture, farmers rely heavily on weather information to optimize planting schedules, fertilizer application, irrigation management, and harvesting. Reliable weather data helps reduce crop losses and prepare for the risks posed by extreme weather events such as droughts or heavy rainfall. The use of weather stations in precision agriculture has become particularly valuable in regions that face climate variability, ensuring both food security and sustainable farming practices.

In the field of aviation, accurate weather monitoring is indispensable for ensuring flight safety. Parameters such as wind speed, wind direction, cloud cover, and visibility must be constantly observed to guide take-off, landing, and in-flight operations. The integration of weather station data with air traffic systems has significantly minimized risks associated with turbulence, storms, and low visibility, thereby safeguarding both passengers and crew.

Weather stations also support transportation and maritime activities [7]. For land transport, accurate forecasts reduce risks associated with heavy rainfall, fog, or storms, allowing for safer route planning. In maritime operations, weather and wind data are essential for navigation, port management, and fishing activities. For countries such as Indonesia, characterized by vast archipelagos and a heavy reliance on maritime trade, the availability of localized weather station data is crucial for minimizing disruptions and accidents at sea.

In the area of disaster mitigation, weather stations contribute to early warning systems that alert governments and communities about potential hazards such as floods, cyclones, or heatwaves. The ability to detect rapid atmospheric changes provides valuable time for preparing evacuation plans, protecting infrastructure, and ensuring public safety. In Indonesia, where natural disasters frequently intersect with population centers, real-time weather monitoring is a crucial element of national disaster management strategies.

Beyond these traditional sectors, weather stations are also increasingly utilized in industrial applications. Portable weather stations are widely employed at construction sites to ensure worker safety and to monitor conditions that may affect structural stability. Moreover, renewable energy sectors such as solar and wind power depend on continuous weather data to optimize energy production and ensure operational efficiency.

In addition to these sectors, weather monitoring is gaining relevance in Islamic astronomy and scientific observation programs. Accurate meteorological data provide essential context for Hilal's observation [2], dawn (Fajr) studies[10], and other celestial monitoring activities. For observatories like OIF UMSU, integrating weather station data into observation reports strengthens the credibility of the outcomes by clarifying whether atmospheric conditions, rather than astronomical impossibility, hindered visibility. Thus, the roles of weather stations extend beyond conventional fields of application, offering significant contributions to both scientific and religious domains..

4. Challenges and Solutions

Although IoT-based weather stations have introduced significant advancements in meteorological monitoring, several challenges remain in their implementation and sustainability [11]. One of the foremost issues is security and privacy. Because IoT weather stations transmit large volumes of data through digital networks, they are vulnerable to cyber threats and unauthorized access. Without strong encryption protocols, regular software updates, and cybersecurity safeguards, weather data may be compromised or manipulated, reducing trust in the systems that rely on it. For observatories and institutions, particularly those that publish official hilal observation results, maintaining data integrity is critical to ensuring credibility.

Another significant challenge concerns interoperability. IoT-based weather stations are manufactured by diverse companies, often using proprietary systems and protocols. This lack of standardization can hinder data sharing and system integration. The adoption of open standards and universal protocols would ensure that different weather monitoring devices can seamlessly communicate with one another. In the context of Islamic astronomy, such compatibility is especially important, as hilal observation programs often involve multiple observation posts spread across vast geographical regions. Standardized data transmission would enable local observatories, such as OIF UMSU, to share atmospheric readings with national and even international networks in real-time.

The issue of data storage and management also poses a significant challenge. IoT-based systems generate vast datasets over extended periods, requiring robust storage solutions. Efficient management through cloud-based or edge computing systems ensures that data is not only stored securely but also processed rapidly for immediate decision-making. For Islamic astronomy, this capacity is vital during time-sensitive events such as the first sighting of the lunar crescent, when delayed access to weather information could affect the credibility and timeliness of rukyat reports [12].

Cost is another limiting factor, especially for smaller institutions, rural observation sites, or community-based initiatives. The installation and maintenance of IoT-based weather stations, along with ongoing subscription fees for cloud services, can place a heavy financial burden on organizations with limited resources. To address this, flexible subscription models, shared data networks, and the development of lower-cost open-source alternatives could help broaden access to weather monitoring technology. For observatories like OIF UMSU, collaborations with universities, government agencies, and local communities may also reduce costs while expanding coverage.

Finally, connectivity dependence remains a pressing issue. IoT-based weather stations rely heavily on stable internet or wireless connections for the transmission of real-time data. In remote or coastal locations, where Hilal observations often take place, network instability can disrupt data flow and undermine the benefits of IoT integration. To overcome this limitation, alternative technologies such as mesh networking or satellite-based communication systems can be adopted to ensure reliability even in areas with poor connectivity.

In summary, while IoT-based weather stations have enhanced the scope and accuracy of meteorological data collection, their full potential will only be realized if these challenges are addressed through robust cybersecurity measures, universal interoperability standards, efficient data management, affordable access models, and resilient communication systems. For Islamic astronomy, overcoming these barriers is crucial to seamlessly integrate atmospheric monitoring into hilal observation programs, fajr studies, and broader scientific endeavors, thereby ensuring both accuracy and reliability in religious and scientific decision-making.

## IV. Conclusion

Weather stations are no longer limited to general meteorology; they have become indispensable tools in Islamic astronomy. Their ability to provide real-time atmospheric data enhances the accuracy of hilal observation, prayer time determination, and Islamic calendar studies. In the context of modern rukyat, these tools are crucial in explaining discrepancies between astronomical predictions and field reports, especially in regions with unpredictable weather. The example of OIF UMSU demonstrates how combining weather stations with instruments such as all-sky cameras, Sky Quality Meters, and CCD telescopes can create a more holistic observation framework. By integrating IoT and artificial intelligence, weather monitoring systems strengthen both scientific and religious observatories, bridging the gap between hisab and rukyat.

Future innovations should prioritize the development of portable, low-cost, and solar-powered weather stations designed explicitly for Islamic astronomy observatories. Such advancements would enable more consistent data collection across Indonesia and the wider Muslim world, ensuring that hilal observations and related programs are conducted with greater reliability, transparency, and scientific accountability.

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