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Solar Powered Smart Climatology Analyzer and Support system for Air Traffic Control

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Abstract: As pilots land on runways, they need accurate and timely weather reports that will allow them to safely land aircraft. However, due to rapid and unpredictable changes in weather, there are many limiting factors to safe landings for pilots; such as limited terminal and center approach airspace, very limited visibility and high wind speeds; all of which can create a panic for pilots when attempting to land an aircraft. The standard base line for obtaining Real-Time Weather Movies (RTWS) is through ground-based equipment used for Reporting Agency Status Reports (MET), based on the level of activity at each airport MCT (Control) Meteorological Data Reporting (MCDR). However, normally only one time in 30 minutes can the ATC's (Air Traffic Control) receive MET inputs, and therefore would consider ATC input for normal weather communication between ATC and MET. When a pilot is requesting Supervised Command and/or of ATC's MET at any given time, under inclement weather, and the communication is delayed; the pilot has no means of receiving MET input via ATC until they have received any MET input prior, thus causing panic for all involved during an Unusual Weather event. A change to this method is necessary to meet current and projected future demands, based on Modernization Needs with Voice/Data Communication transfers (as opposed to A/C/R/T able) and AI Operational Weather Communication System (AIWS). The proposed research outlines the development of a fully functional and autonomous weather monitoring device that complies with both IMD (India Meteorological Department) and ICAO (International Civil Aviation Organization) guidelines. The weather monitoring devices will utilize runway based sensor systems (including but not limited to temperature, RH, wind speed and direction, ambient light level, fog density at touchdown point and sky visibility) to collect data on atmospheric condition of the atmosphere, enabling pilots to make more informed weather-related decision while simultaneously lowering the probability of runway excursions by enabling more improved systems. The weather monitoring system will ultimately make use of renewable hybrid power sources as well as provide battery backup for continuous functioning, providing maximum situational awareness and minimizing possibilities of runway excursions by providing pilots with high quality weather information.

Keywords: Aviation meteorology, Automated Weather Observation System, Embedded system, Runway visibility, Fog detection, Wind monitoring, Renewable energy, Real-time data acquisition, IMD and ICAO standards, Aviation safety, Pre-landing weather observation, Safety automation, Data transmission.

I. Introduction

Aviation is growing increasingly reliant on meteorological data that is accurate and reliable in order to The current aviation industry relies heavily and increasingly upon accurately and consistently recorded weather information to safely operate commercial and general aviation aircraft.

Landing is considered an unsafe part of the operation of an aircraft because many environmental variables that can affect a runway's capability for landing (e.g. wind shear, etc.) can create conditions that make it difficult to carry out a safe landing; these include decreased visibility, wet runways, and/or the formation of fog, temperature, (relative to performance), etc. All member countries of the International Civil Aviation Organization (ICAO) and the Directorate General of Civil Aviation (DGCA) are required to report on weather conditions in accordance with prescribed formats such as METAR, SPECI, TAF, aerodrome warnings, and climatological summaries. The ambient temperature around airports and runways has a direct impact on the amount of air density available for aircraft at the start of the landing process. If the ambient temperature around an airport is warmed then the amount of air that is available for the performance of an aircraft during a landing will be reduced, consequently increasing both the amount of land required for a successful landing as well as the speed at which the aircraft needs to approach the runway; therefore, temperature directly affects the performance of aircraft during the landing process. In addition, an increase in the relative humidity of the air surrounding an airport will lower the density of the air available for the performance of an aircraft, resulting in a longer runway length and higher power settings required for a successful landing. Furthermore, an increase in relative humidity can also adversely impact the quality of radio communication, as well as the use of walkie-talkies. Thus, the relative humidity of the air within an airport environment has the most influence on the ability of an aircraft to safely complete its landing.

The wind can greatly affect the speed and stability of an aircraft when it lands, and it can be particularly challenging for pilots when there are high crosswinds that push the plane sideways and require them to make constant corrections. Therefore, pilots need to be aware of these conditions before attempting to land. If winds are particularly strong and gusty, or if the wind shifts direction during the approach, a pilot may have to abort their landing for safety reasons and never be able to successfully land.

The changing directions of the wind also create difficulties for pilots because they must correct for their drift, align the aircraft with the runway, and manage the performance of the aircraft, all in an uncertain environment. Therefore, many pilots do not feel capable of making the decision to land based on their own experience, and instead will ask for expert help or abort their landing in India.

In India, there are dedicated MET stations at every airport, smaller airports are served by AMOS, while the major FIRs (Chennai, Kolkata, Mumbai and New Delhi) have dedicated MWO/AMO services.

There are also some other instruments available in addition to the weather stations, such as special climatology software products for tropical cyclone advisories at Bengaluru and Surface Stations, telecom divisions and upper air instruments centres available in various places in India.

Currently, AMS completes daily operations at the airport but with an increasing amount of air traffic as well as increased unpredictability in weather conditions and the development of remote airports under a UDAN scheme, there has become a growing need for partially automated (sensor-driven) weather monitoring to capture the changing conditions. There is therefore a proposal for the creation of an automated weather data acquisition and processing system to replicate the operational functions presently fulfilled by AMS and AMO respectively, so as to enhance their autonomy and to reduce their dependence upon human resources. The proposed system will deliver aviation weather reports in a structured format and will contain a genuine real-time measurement system for airport-specific runway conditions in order to minimize the risk associated with runway excursions which are the leading cause of aviation-related operational events worldwide. All information currently sent to AOCC (Airport Operational Control Centre) via a localized network and to the aircraft using wireless communication during the abnormal weather events, will continue to be transmitted using standard code number. There is currently no transmission of an entire climatology record to the pilot to aid in making an informed decision.

Environmental fog can impact the runway visual range (RVR) to such an extent that it can prevent a pilot from making a landing decision. Various types of fog include radiation fog, advection fog, upslope fog, frontal fog, steam fog, and ice fog. Loss of visibility is an important factor because it limits an airport's ability to operate; it also causes aircraft to have a longer landing process than they would normally have because visual cues are not present when trying to land at their respective runways. Ambient light analysis is an equally important variable as visibility for gathering data on fog and visibility.

II. System Overview

A proposed automated meteorological monitoring and reporting system will enable autonomous real-time observations and reporting to the Air Traffic Control (ATC) center of runway weather conditions. The proposed integrated monitoring system consists of many individually operated and distributed sensors that collect the various meteorological parameters required for an aircraft's safe and appropriate pre- and post-landing performance. The individual sensor (temperature, humidity, fog density, visibility range, wind speed, and wind direction) collects statistical meteorological data from its high-performance sensor. After each sensor collects its data, it transmits the information via wire, under an RS-232 serial protocol, to the Central Data Acquisition Module (CDAM). The input of each sensor is civilly refined through filtering and analog-to-digital conversion of the input (to 10 bits) via the inbuilt, programmed functionality of an embedded microcontroller SAR ADC.

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The CDAM receives the converted data and applies rules from IMD, ICAO to create formats of compliance with aviation; specifically, METAR's, SPECIs. The CDAM then sends the processed data (from the CDAM) to ATC via either a physical interface (RS-232, RS-485) OR OPTIONAL wireless Internet of Things (IoT) communication channels to provide an airport-specific scalable solution. The CDAM is powered by a hybrid modular power supply, which may be powered by either a REGULATED electrical supply OR a RENEWABLE electrical supply and will continue to operate without depending on a standard electrical grid supply (this enhances the redundancy of the CDAM). The hybrid power supply provides resilience to dependence on power for operational purposes and allows for installation in "regional," "remote," and/or "developing" aviation environments.

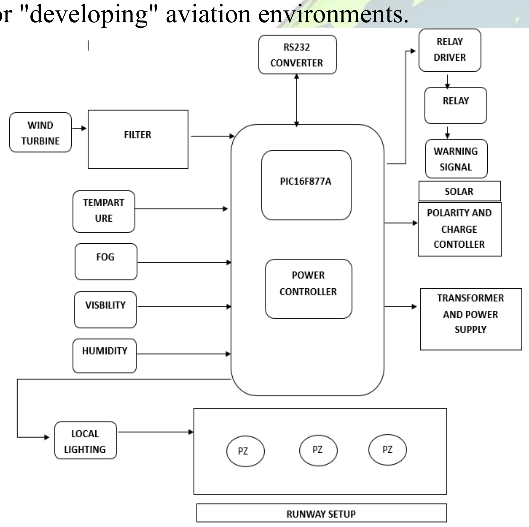

Fig.1.BlockDiagramofProposedScheme

The Figure.1 illustrates Proposed system architecture consisting of integrating runway level weather sensors with the PIC16F877A microcontroller for data acquisition, processing, and communication.

III. METHODOLOGY

Using a systematic approach and following the appropriate procedures for creating an automated meteorological observation system will allow for a smooth flow of aerospace traffic reports to the users of the system. The starting point of the flow will be determined by the real-time collection of weather observations from the runway, the second step will be sending those observations to digital processors, which, in accordance with transportation rules and regulations, will convert the data into digital codes before formatting them and sending them to individuals responsible for making operational decisions. The flow diagram presented illustrates an accurate distribution of the data that has been collected concerning the various meteorological conditions and subsequently formatted to meet the standards established by the aviation department and provided to executive personnel involved in making the appropriate operational decisions regarding safe operation and landings of the aircraft.

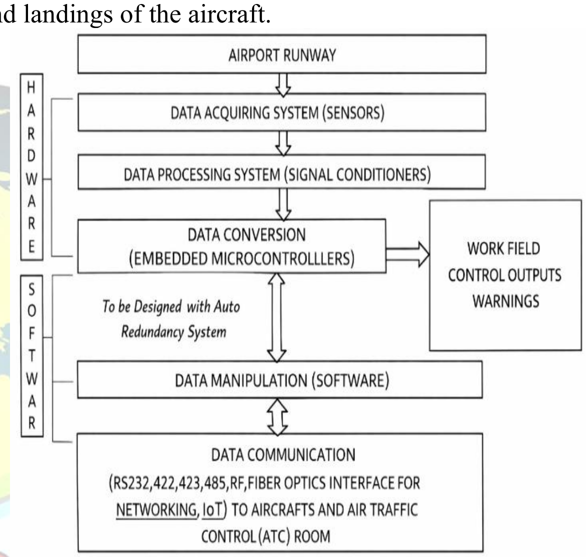

Fig.2.FlowDiagramofProposed Scheme

The Figure.2 describes the process flow of the system, which includes the processes involved in data acquisition, signal processing, aviation data encoding, and data transmission to the ATC center.

The process flow description of the system are as follows:

A. *Data Acquisition:*

Initially, sensors were used to measure weather conditions around the runway. The temperature and humidity were measured using thermistors while infrared diffused sensor and infrared through-beam sensor received fog density measurement as well as visibility measurements. Wind speed was measured with an anemometer and the wind direction was obtained from a ball-switch sensor. The sensors provided a continuous output circuit and were installed on the runway to measure local micro-climate conditions that affect the approach and landing phase.

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B. *Data Processing*

Once the signals from the sensor were received, they underwent processing in order to verify the quality and accuracy of the measurements received at each sensor. Signal Conditioning techniques are employed to account for any uncertainty and fluctuations in the sensor signals caused by electrical noise (or other types) or also due to atmospheric transients (e.g. lightning strikes). After the sensor signal has been processed, the results are scaled to appropriate operational limit requirements ensuring that the measurement of weather conditions is consistent with ICAO and IMD tolerance limits.

C. *Power Generation*

Analog data will be converted into digital data by means of the successive approximation method using an ADC. Once the data is processed, the onboard microcontroller will convert the measured data into numerical data with enough precision and accuracy for reporting on aviation weather. The architecture characteristic of the specific type of ADC architecture will allow for real-time processing of the data without introducing delays in getting the measured data.

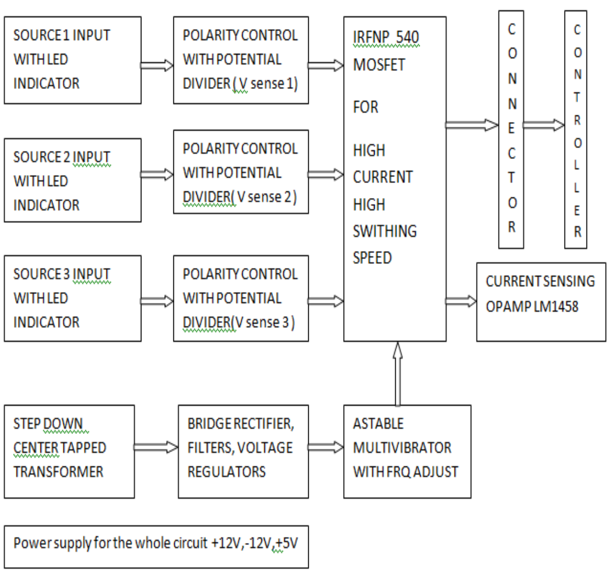

Fig.3.Power Generation Block Diagram of the Runway

The Figure.3 shows the renewable energy system implementation along the runway, where the integration of micro wind turbines and piezoelectric modules for power generation and regulation for the continuous operation of the system is clearly demonstrated.

D. *Communication and Data Transmission*

The embedded controller will convert digital data into meteorological standard based on aviation specification, and utilize this data to determine dew point, wind direction (°), visibility class and weather conditions. The output of processing will be in accordance with ICAO Annex III METAR and SPECI specifications so will be accepted by current airport meteorological systems, and displayed for air traffic control operators.

E. *User Interface, Data Visualization, and System Testing*

That weather data made available through an easy to use interface can be accessed not only in numerical on the numerical scale but also through the use of graphical representations. This feature enables Air Traffic Controllers and Pilot's operating into that specific airport to quickly interpret real-time surface runway condition reports such as visibility reports, wind velocity reports, and fog report levels. To ensure Sensor systems are performing accurately and to provide efficient operational communications between all components of the Sensor systems (Air Traffic Controllers have communication with all air traffic control towers), operational and efficient testing of the Sensor Systems is accomplished through realistic operational simulation of actual flight activities. Based on the results of the test, appropriate modifications are made for increasing reliability and reducing latency within the sensor system to achieve maximum performance.

Once validated, the reported data collected during aviation weather system testing will be communicated over a hard (wired) Interface using RS-232/RS-485, or via an optional wireless module, to the Control Station to generate the Aviation Weather Report that will be communicated both electronically and remotely in areas where sound infrastructure is not readily available.

The communication format of the Aviation Weather Reports protects the end-user's data by providing timely, secure, continuous and uninterrupted delivery of data that is needed by Air Traffic Controllers and Pilots to make timely and accurate operational decisions when operating/runway landing/operating.

IV. TECHNICAL IMPLEMENTATION AND DESIGN DETAILS

This weather measuring system provides an autonomous solution for providing on-the-runway accurate weather measurement. The system uses a built-in 10-bit successive

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approximation analog-to-digital converter from the integrated embedded microcontroller. The system utilizes a 10 MHz crystal, providing the precise timing required to monitor environmental changes under aviation standards. The system controller interfaces with rugged sensors, allowing the embedded microcontroller to accurately gather and process the data from the systems' various sensors. The sensors are high performing and accurate with construction materials, reliability, temperature variations, and atmospheric change detection capability, which is required in defense operations.

The next section will provide a short description of each component utilized in the system.

A. Embedded Control Unit:

The real-time processing and interpretation of sensor measurements from the environment by the Embedded Control Unit will allow for low latency and therefore will meet all aviation sector's timeline requirements with great efficiency.

B. Sensor Integration:

The system's sensors are NTC thermistors (temperature and humidity), Infrared sensors (fog and visibility), an anemometer (wind speed), and a wind direction sensor (set up with a directional vane and switching output).

C. Signal Acquisition and Conditioning:

The signals from the sensors are analog; therefore, they require processing to filter out noise and correct any offset or apply scaling; thus, resulting in an improved reduction of signal to noise ratio, and as a result produce accurate digital representations of the measured parameters.

D. Communication Interface:

Processed and converted weather data will also be transmitted via a wired communication method to provide compatibility with existing meteorological and Air Traffic Control (ATC) systems that are necessary for the safe and efficient operation of all airport operations. Communication mediums used include RS-232 for short distance communications and RS-485 long-range communications.

E. Power Regulation and Backup:

The power control and backup sections use a transformer to reduce the input voltage, a bridge to rectify the current; filters will smooth out the current, and linear regulators will provide a steady DC power supply. The unused renewable power from the wind and sun will be used to produce additional power and keep the system running continuously.

F. Software and Aviation Encoding*:*

Embedded software is primarily used to perform calculations on raw sensor data according to the ICAO and IMD standards for proper aviation code formats putting it into predefined threshold values will produce a final reported.

V. Results and Discussions

The final evaluation of the system will include an actual, real world test based on several different airport runways with operational conditions. The purpose of this test will be to assess actual operational and performance capabilities of the system, its level of accuracy and precision, the ability of the system to operate properly and to be viable long term, as defined by ICAO and IMD. Data that is generated by the system from some of the certified meteorological offices that it consists of will be used for determining if these organizations are providing accurate solutions in a timely fashion.

This final monitoring test will verify that the system will automatically monitor and record those weather parameters as described in ICAO and IMD, under the aviation environment. Furthermore, this evaluation will confirm that this system will be able to allow the integration of new types of sensors that will monitor and report renewable energy sources such as sunshine, wind and rain. The results show that the system will provide timely, accurate results prior to a commercial aircraft landing without requiring any additional supporting infrastructure. The following factors are as follows:

a. System Performance:

The findings from a joint evaluation of the system show that the prototype is able to produce high quality and high resolution weather data, as well as to reduce the amount of signal loss received. In addition, the final output (data) will be compared to a certified reference FAA airport weather station, and demonstrate strong correlations with one another for the following weather parameters: wind speed, temperature, relative humidity, visibility, and fog intensity.

The average latency of output from the prototype during processing was approximately 200-300 milliseconds, which provides operational personnel with timely access to appropriate, relevant weather data. The processed output data from the prototype were also created according to the METAR/SPECI format specifications. Therefore, all of the data produced by the prototype are in standard meteorological report formats that will be recognized by air traffic control. Thus, to determine whether the prototype has successfully achieved all functional and operational requirements, and whether the operation of the prototype can be successfully transitioned to an operational environment,

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these data must be classified and the assessment results assessed. The evaluation results will be classified according to the following major parameters:

b. Renewable Energy Integration:

The micro wind turbines and piezoelectric energy harvesting devices worked together to supply power necessary to power your sensors and processing equipment while conducting continuous tests. During operation, the utility grid will not be used for any support; however, enough power will be available for the generation of real-time meteorological data to help support and be independent of the utility grid.

This enables users to maintain power supply through periods of high air traffic at airports; therefore, it verifies the self-sustaining design of the system. As a result, the ability to operate independent of power obtained through the grid provide for the development of remote resource limited airports through regional growth strategies outlined for use at all regional growth airports.

c. Challenges Encountered:

At airports where the volume and duration of flight operations are moderate or greater, renewable energy sources can easily be utilized. However, there are limitations in the amount of energy stored for renewed use as a result of only a few aircraft flying for long periods of time. The intermittent availability of renewable energy also requires the development of better battery storage capabilities or hybrid energy storage to ensure continuous operation through periods of heavy, or severe weather events (including summer heat waves or heavy rain). The characteristics of the overall system have shown that the next design will use optimized energy storage systems, and improved energy harvesting systems by using renewable energy source powered embedded systems.

d. Cost Effectiveness and Scalability:

The Low Power Embedded Design Architecture tolerates the deployment to regional and international airports with little change to their infrastructure. Using low-cost sensors and energy-efficient processors greatly reduces the cost of installation per sensor.

The comparison of the recommended Self-Powered Weather Observation System for Airport Using Renewable EnergySystem and those described in papers [1]- [16] has been completed with an emphasis on some of the important factors and given in the Table 1.

Ref. No.	Application Domain	Core System Architecture	Aviation & Runway-Level Capability
[1]	Mobile-integrated environmental monitoring	Cloud-based sensor station that can be visualized on a mobile device.	No ICAO/IMD encoding; non-aviation; station-level locations only.
[3]	IoT-based weather monitoring	ESP32-based IoT sensing platform	Non-aviation; no structured encoding for aviation; no runway deployment for associated sensors.
[4]	Renewable airport infrastructure	Integration of renewable energy sources into the grid.	Energy-oriented; no method for encoding weather data.
[9]	Aviation wireless sensor networks	A WSN architecture designed specifically for an aviation environment and operations.	Optimization of sensor network performance.
[10]	Runway wind distribution modeling	Statistical modeling of wind speed and direction.	Meteorological modeling specific to each of the runways; no real-time data available from information sources.
[16]	Fog detection & visibility enhancement	Sensor-based modeling of visibility.	Sophisticated methods for detecting fog.
Proposed Work	Runway-level aviation meteorology	Distributed embedded sensing that utilizes hybrid renewable energy and edge processing.	ICAO/IMD-compliant generation of METAR/SPECI; distributed touchdown zone data; no requirement for an electric grid; integrated reporting to real-time ATC and pilots.

Table 1. Comparative Analysis of Existing Systems and Proposed Runway Level Aviation Meteorology System

Even though Paper [9], Paper [10], and Paper [16] have made contributions to aviation weather technologies; using

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papers to support weather technologies provides advantages against existing systems. They continue to be viewed as modular (i.e. separate) aviation weather technologies. In addition to the contributions made by Paper [1] and Paper [3], both papers contain electronic devices designed to monitor an environment for data that can be stored using the IoT, and both provide a cloud-based display of that data.

Nonetheless, both papers fail to meet the required Air Transport Association Standards for the Aviation Field which means these papers do not qualify as records of climatological data for aviation use. Furthermore, neither manuscript provides an indication of how to format an ATC communication protocol nor does either paper provide an appropriate description of a designation for a touchdown area.The merger of the four processes (sensing, processing, energy self-sufficiency and aviation compliant data reporting) will allow for a seamless exchange of data between runway-based sensors, the various FAA ATC systems and the various flight deck based (cockpit) decision support systems. This merger will allow for real-time data to support an uninterrupted continuous operation (i.e., prior to touchdowns and following touchdowns).

The hardware implementation and present available outputs from the prototype AWOS will be provided below to provide evidence of the functional integration of the various data sources of the sensors that comprise the Climatological Monitoring System for the airport.

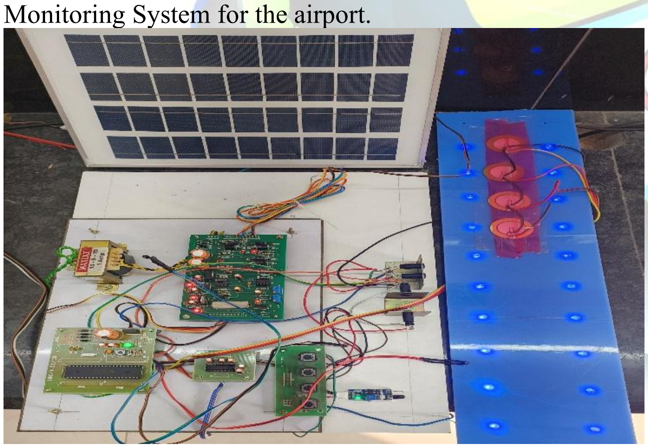

Figure 4: Final AWOS Prototype

Figure 4. shows the integrated circuit (PCB) with Temperature, Humidity, Luminosity, Fog Sensors with Wind Speed Sensors all interfaced with a microcontroller for the real-time acquisition and pre-processing of meteorological data.

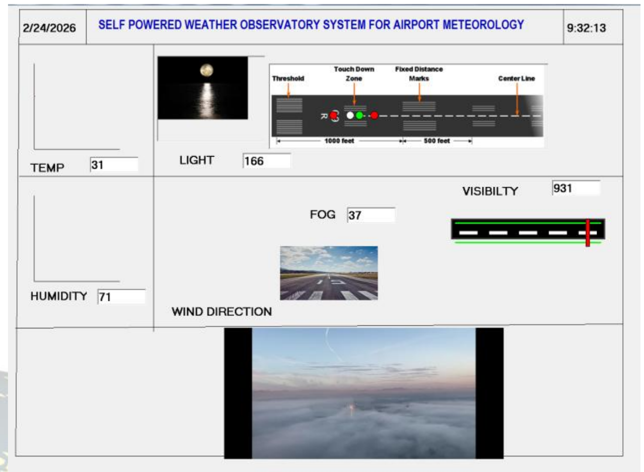

Fig.5.The visual shows that the temperature is okay, no light, poor visibility, no fog, touchdown point of the aircraft.

The Figure.5 gives us the expected system performance during the nightwith no presence of light with real-time runway level weather data and the self-sufficiency of energy with respect to the ICAO and IMD aviation standards.

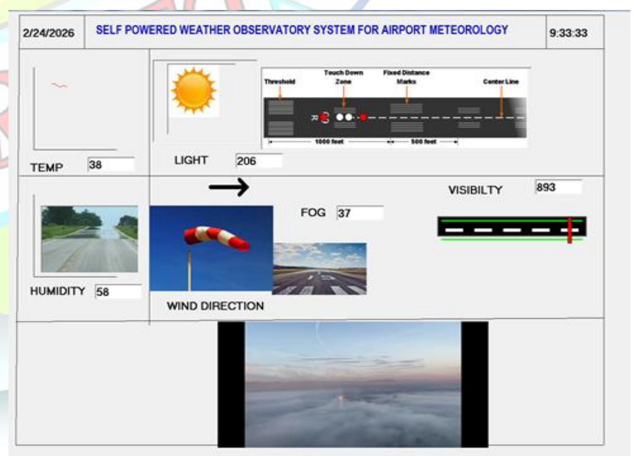

Fig.6.The visual shows that the temperature is okay, presence of light, poor visibility, no fog, direction of wind.

The Figure.6 gives us the expected system performance during the day with presence of light with real-time runway

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level weather data and the self-sufficiency of energy with respect to the ICAO and IMD aviation standards.

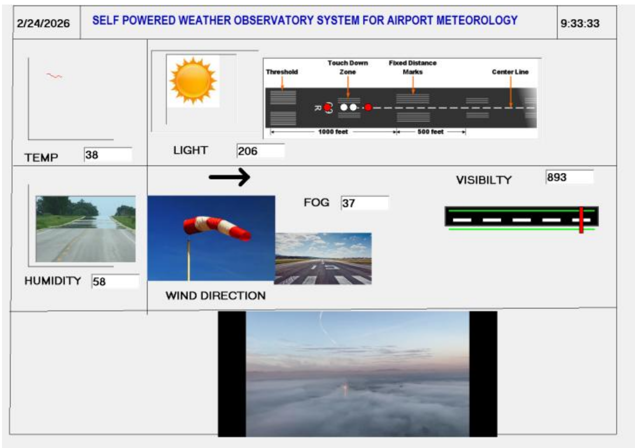

Figure 7: The visual shows that the temperature is okay, with light, clear visibility, no fog, wind direction, touchdown point of the aircraft.

Figure 7. gives us the expected system performance during the daywith presence of light and wind direction indication with real-time runway level weather data and the self-sufficiency of energy with respect to the ICAO and IMD aviation standards.

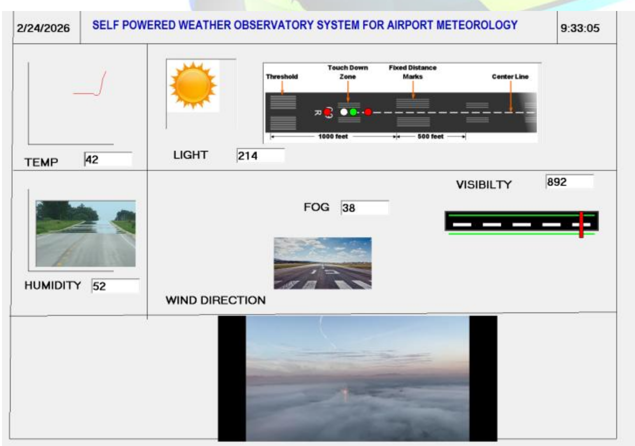

Figure 8: The visual shows that the temperature is high, presence of light, clear visibility, no fog, touchdown point of aircraft.

Figure 8. gives us the expected system performance during the daywith presence of light, temperature and clear visibilitywith real-time runway level weather data and the self-sufficiency of energy with respect to the ICAO and IMD aviation standards.

So Overall, this system serves as the target product for the future autonomous Meteorological Support System (MSS) for use within the aviation sector, being that it lends itself well to supporting aviation safety via the on-going collection of environmental data on a continuous basis.

VI. Conclusion

Real-time meteorological data at the runway level can greatly enhance the safety of aviation through the use of an Automated Weather Information System (AWOS).

AWOS is both reliable and scalable providing accurate meteorological data that meets the requirements of the aviation field system. The use of automated weather measurements provides the incorporation of digital signal processing, as well as aviation encoding standards to produce real-time, accurate and timely meteorological data. By using fully automated weather measurement, there is no requirement for manual observations, and the measurements produced by the AWOS meet both the ICAO and IMD requirements. Testing has shown that the available weather measurements from AWOS show high correlation to certified weather stations, low latency in processing observed weather and accurately measuring critical weather parameters including fog, visibility, temperature, humidity and wind. The use of renewable energy sources tosupport

While this system shows the successful execution, many improvements are found more for the development in the future:

a. AI/ML Integration:

Utilising sophisticated machine-learning techniques to forecast the weather improves the ability of the system to predict when information about the weather will be available and increases the level of proactive assistance airports have received.

b. Energy Storage Optimization:

With use of new battery technologies and intelligent systems for managing energy, we will be able to manage electricity consumption so that we can continue to operate without relying on the power grid.

c. Scalability and Network Integration:

In the future, as these systems develop, we will be able to provide real-time data exchange between airports to enhance safety in aviation and the Operational Division of Aviation.

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d. Enhanced Sensor Capabilities:

It should be relatively easy to integrate the proposed systems with additional sensors, for example, atmospheric pressure, cloud cover, etc., to provide a more robust meteorological dataset.

This prototype has proven to be both reliable and scalable and has been used to illustrate the benefits of continued environmental monitoring on improving safety. Future development of the prototype will result in continued improvements to its reliability, performance, and decision support capabilities through predictive analytics for short term weather forecasts..

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