Atmospheric dynamics and early warning system low level windshear for airport runway hazard mitigations

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Abstract. Natural disaster nowadays often occur in Indonesia due to climate change, especially those related to atmospheric dynamics anomalies. The statutory event of atmospheric turbulence statistically is quite significant in its improvement. This is an important issue to conduct research both in the analysis of atmospheric dynamics and early detection solutions for these events. The Windshear phenomenon is an atmospheric turbulence disaster that occurs below an altitude of 3000 feet, often known as low level windshear (LLWS), which is very dangerous for planes taking take-off or landing. Its effect on the aircraft will result in increased airflow on the wings, so this increased airflow will result in a sudden increase in aircraft speed. If the pilot is not aware of the indication of the windshear, he will instinctively throttle back to reduce/compensate for the aircraft's speed. However, once the aircraft passes through the windshear zone, the wind suddenly turns into a downdraft. The design of windshear early detection devices has been developed to complement research on the dynamics of the atmosphere. The results obtained are anomalous changes in temperature and atmospheric pressure at this time, and the windshear sensor can detect it well.

1. Introduction

Windshear is a change in airflow in terms of direction and speed accompanying a thunderstorm which changes air pressure and occurs only in a limited area, and in a short time, this airflow rotates outward while moving downwards. This can occur either horizontally or vertically and is most commonly associated with strong temperature inversions or density gradients. Windshear that occurs below 3000 feet, often known as low level windshear (LLWS), is very dangerous for aircraft that are taking off or landing. The effect on the aircraft will result in an increase in airflow on the wings so that this increased airflow will result in a sudden increase in aircraft speed. If the pilot is not aware of the indication of the windshear, then instinctively, he will throttle back to reduce/compensate for the speed of the aircraft. However, once the aircraft passes through the windshear zone, the wind suddenly turns into a downdraft. This incident reduces the airspeed on the wing, which correlates with the loss of lift (stall) and the aircraft is likely to fall considering that the altitude is not sufficient for recovery [1,2,3].
Figure 1. Number of natural disaster events in Indonesia during the period 2000 to 2020. [4]

Based on BNPB data, natural disasters caused by anomalous dynamics of the atmosphere in Indonesia occupy the highest number, as in Figure 1. Floods are followed by turbulence disasters. Turbulence disasters, as mentioned, include Cyclone, Typhon, CAT, and windshear, with events during the period 2000 to 2020 (BNPB data). In this research, the design of windshear detection devices for early detection of the turbulence disaster has been carried out [4, 5, 6].

In general, there are 4 (four) sources that cause low level windshear (LLWS), namely frontal activity, thunderstorms, temperature inversions, and surface obstructions. In the frontal activity, LLWS is identified by a temperature difference at the front on the surface, which is 10 °F (5 °C) or more, and the front part moves with a minimum speed of 30 knots. Usually, these two things give clues to LLWS.

In the case of thunderstorms, it will cause convective weather with temperature inversions in the form of wind gusts, downdrafts, microbursts, and gravitational waves which all form LLWS. In addition, the topography of the land surface (surface obstructions) in the form of mountains, rivers, ravines, and including a large hangar beside the airport runway will also change the wind pattern, which contributes to LLWS. A microburst is a windshear that comes from cold air flowing from the bottom of a storm cloud in a pattern like an inverted mushroom plant. Microburst usually results from cumulonimbus (Cb) clouds. When a storm occurs in the dark cloud, a microburst appears, which is the pilot's main enemy, and anyone will try to avoid it. Because if there is a downdraft (downward force) caused by a microburst, there is no mercy that the plane of any size can be slammed down. Several fatal airplane accidents have occurred due to this microburst phenomenon. One of the most famous is the crash of Delta Air Lines' Lockheed TriStar flight 191, just before landing at the Dallas-Fort Worth international airport in Texas, United States, on August 2, 1985. Figure 2 shows the effect of microburst on aircraft flight both during take-off and landing [7, 8, 9]. The purpose of this research is to design a windshear early warning device based on an anemometer sensor and signal processing model.

2. Experiments details
The development of computer technology allows an idea that combines dynamic analysis of the atmosphere and sensor technology to be combined into a windshear early warning tool. The low level windshear detection system on the airport runway has several important parts, including: sensors, signal conditioners, signal processing, and display. The sensor functions to scan the physical quantities to be measured into electrical quantities. Signal conditioners have a role in strengthening the amount of electricity so that it can be processed by the signal processor. The signal processor will convert electrical quantities into measurable quantities for analysis and measurement purposes. While the viewer functions
to display the results processed by the signal processor, the viewer can be done in the form of an LCD display or a computer dashboard to make it easier for users to perform analysis. The block diagram of the low level windshear detection system on the airport runway is shown in figure 2 [10,11,12].

Figure 2. Block diagram of the general measuring system

The capabilities offered by a low level windshear detection system on airport runways are as follows:
1. Detects a low level windshear
2. Early warning of low level windshear
3. Low level windshear detection system can be accessed via web and LCD display
4. Tail Wind Alert Specifications:
   Tailwind Component (180 degrees to runway azimuth) with alerts starting from:
   \( \geq 5 \) knots \( \geq 10 \) knots \( \geq 15 \) knots
   Cross Wind Alert:
   Crosswind Component (90 degrees left or right to runway azimuth) with alerts starting from:
   \( \geq 10 \) knots \( \geq 20 \) knots \( \geq 30 \) knots
   Windshear Alert:
   The amount of shearing wind component (any direction)
   \( \geq 10 \) knots \( \geq 15 \) knots
   Warning if there is crossed wind \( \geq 10 \) knots
   The alert setting can be modify-able because for various types of environments (especially given runway dimension and condition / general friction) it will apply different limitations (more binding / more limiting) [13,14,15].

Figure 3. The flow chart of the data acquisition process to data processing
Based on these things, in the design of the low level windshear detection system on the airport runway, several sensors of wind speed and direction should be placed at several predetermined points (sensor array). By paying attention to some of these things, it is expected that comprehensive measurement results will be obtained. The anemometer configuration is a wind speed and direction sensor in the low level windshear detection system on the airport runway [16,17].

The flow diagram of the data acquisition process to data processing is shown in Figure 3. In this figure, the process begins with data acquisition from the wind direction and speed sensor, then the sensor data is processed by the signal conditioner and ADC. Then the output from the ADC is processed by the data processing system to be able to detect LLWS, if no LLWS is found, the sensor will continue to scan the wind direction and speed. However, if LLWS is known, the system will warn ATC via LAN connection and can be accessed via the web. ATC will convey this information to the pilot so that the pilot can immediately follow up [18,19].

![Data processing method for LLWS detection](image)

**Figure 4.** Data processing method for LLWS detection

While the data processing method for LLWS detection is shown in Figure 4, based on this figure, the data acquisition process plays a very important role. The next stage is pre-processing the data. In this process, the problematic data filter is carried out. The next stage is to process data with divergence analysis to determine whether there is LLWS or not. Meanwhile, the final stage is analysis or verification of LLWS warnings [21,22].

3. Results and discussion
The output from the sensor will be amplified by an amplifier (signal conditioner) then the analog quantity will be converted by Analog to Digital Conversion (ADC). The ADC output will be processed by a signal processor, in this case using a Raspberry Pi, which will convert the electrical quantity into
wind direction and speed. Raspberry Pi has several features, namely Micro SD which functions as a hard drive, USB port, Ethernet port, audio video output, HDMI Video, 400-700 MHz CPU, and most importantly, the Raspberry Pi has a GPIO pin that functions to interface with various devices electronics (Stone, 2012), physically the form of the Raspberry Pi is shown in Figure 5.

![Figure 5. The shape and architecture of the Raspberry Pi [24]](image)

Based on the architecture of the Raspberry Pi, it is possible with a large number of sensor inputs, monitor outputs and data connections via Local Area Networks (LAN), so that this system can be accessed via the web as shown in Figure 6 [23,24].

![Figure 6. Design of low level windshear detection on airport runways](image)

Designing the interface for the windshear application is done by creating a dashboard that is equipped with information as an early warning. The consideration given is that the windshear application is an application for monitoring wind events at a location, so this dashboard approach is the most appropriate
which is used as a reference for making an interface display equipped with notifications in the form of sound and color changes. The design of the windshear application interface is given as follows:

![Interface early warning system windshear](image)

**Figure 7.** Interface early warning system windshear

Low level Windshear Sensor / LLWS prototype has been tested on a laboratory scale. The test was carried out at the Electronics and Instrumentation Laboratory of the Department of Physics, UNDIP. The parameters tested include wind speed and direction, with the treatment comparing the speed and direction measurements of the LLWS prototype with standard tools. The following is the process of testing each parameter:

Testing using a standard anemometer aims to calibrate the LLWS. This calibration is by comparing the LLWS wind speed data with a standard anemometer. Based on the tests carried out, data is obtained as shown in Table 1, Figure 8 below [25,26,27].

| No. | Wind velocity Standard Anemometer (m/s) | Wind velocity LLWS anemometer (m/s) |
|-----|---------------------------------------|-----------------------------------|
| 1   | 1                                     | 0.9                               |
| 2   | 3                                     | 3.1                               |
| 3   | 5                                     | 4.9                               |
| 4   | 7                                     | 6.9                               |
| 5   | 9                                     | 9.1                               |
| 6   | 11                                    | 10.8                              |
| 7   | 13                                    | 13.1                              |
Based on figure 8, it is known that the data from the sensor measurement results show linear data. This is what will be used to calibrate the sensor. As reinforcement data, wind measurements have been made with the addition of speed per unit time. Testing using the Standard Compass aims to calibrate the LLWS. This calibration is by comparing wind direction data on LLWS with standard compass direction. Based on the tests carried out, data is obtained as shown in Table 2 in Figure 9.

**Table 2** Experiment of wind direction for each change in angle

| No. | Standard Wind Direction (Angle Direction) | LLWS Wind Direction (Angle Direction) |
|-----|------------------------------------------|----------------------------------------|
| 1   | 0                                        | 0                                      |
| 2   | 45                                       | 44.7                                   |
| 3   | 90                                       | 90.2                                   |
| 4   | 135                                      | 135.3                                  |
| 5   | 180                                      | 179.7                                  |
| 6   | 225                                      | 224.9                                  |
| 7   | 270                                      | 270.4                                  |

**Figure 8.** Speed Graph Comparison of LLWS and Anemometer

**Figure 9.** Wind direction graph comparison of LLWS and standard compass.
Based on figure 9, it is known that the data from the sensor measurement results show linear data. This is what will be used to calibrate the sensor. As amplifier data, measurements of wind direction have been carried out with changes in each degree which will later be converted to the wind direction by BMKG standard [28,29,30].

4. Conclusion
Based on the above results, a good windshear detection tool has been produced, as an effort to provide accurate information regarding the air condition above the airport by the presence of a low level windshear to the airport operator and pilot, a system that can monitor low level windshear conditions is needed. real-time and automatically informs the monitoring in the form of a low level windshear level condition or in the form of a safe or unsafe sign for take-off or landing an airplane. The precision of this information is needed as part of an effort to prevent accidents that occur.

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