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Road Environment Black Ice Detection Using LiDAR Sensor

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ABSTRACT

This paper puts forth a novel methodology for the detection of black ice utilizing a Lidar Lite v3 sensor. The sensor is a compact, cost-effective, high-precision distance measuring device utilized to discern the angle between asphalt and black ice by modulating temperature and tilt angle. The sensor exhibits a range measurement error rate of approximately ±1 cm, which may result in some errors in distinguishing between black ice and asphalt. This paper highlights the necessity for further research and enhancements to enhance accuracy and proposes a more precise method for detecting black ice.

Keywords: *Black ice, Lidar, Road environment.*

1. INTRODUCTION

In this study, we introduce a novel approach for comparing temperature and tilt angles utilizing the Lidar Lite v3 sensor. Furthermore, we present a new method for detecting black ice by discerning the difference between asphalt and ice based on laser reflection intensity. Despite its compact size and affordability, the Lidar Lite v3 is a highly accurate distance measurement sensor. By employing this sensor to measure the variances in temperature and angle, preliminary data essential for distinguishing asphalt from black ice can be acquired.

It is notable that the performance of the Lidar Lite v3 sensor is not significantly affected by temperature. While temperature variations have a negligible impact, errors in distance measurements may be introduced by the tilt angle of the object and the material of the reflective surface. The methodology for detecting black ice with the Lidar Lite v3 sensor, as proposed in this study, could be integrated with additional sensors or may necessitate extensive calibration. The Lidar Lite v3 sensor demonstrates a distance measurement error margin of approximately ±1 cm. While this level of accuracy is deemed adequate for general applications, there may be instances where differentiation between ice and black ice is not entirely accurate. In light of the necessity for further research and enhancements to improve the precision of black ice detection, this paper proposes a method that involves the measurement and comparison of temperature and angle using Lidar Lite v3 sensors for the identification of black ice. 1 Faculty of Social Sciences and Humanities, Putera Batam University, Indonesia. E-mail: mortigor.afrizal@gmail.com

2. COMPUTING DATA PROCESSING RESEARCH

2.1 Black Ice

Figure 1 demonstrates that despite the considerable focus on the advancement of technologies aimed at averting incidents caused by black ice, a significant hurdle persists due to the substantial time and financial resources necessitated by their design. As a result, a technology that employs a data collection sensor module and a camera has been developed. This technology employs a wireless data transmission system to relay information regarding the prevailing weather conditions on the road surface. It does so by collecting data from a designated section of the road in response to a received information lead signal, which is repeated multiple times. Notwithstanding these advances, several issues remain. The installation process, which is necessary for detecting road surface weather conditions, is both time-consuming and costly. Moreover, the assessment of surface freezing based on light reflectance is susceptible to misinterpretation due to external factors. Furthermore, there is a challenge in identifying freezing under special environmental conditions that do not meet the predefined criteria for predicting ice formation. Moreover, in specific environmental contexts, the established criteria for freezing may not be met, thereby impeding the ability to detect existing black ice.

There is a compelling need for research into the development of more sophisticated technologies capable of accurately detecting and predicting black ice. Artificial intelligence and algorithms based on deep learning may prove instrumental in addressing future challenges. Such technologies, which are equipped with image and pattern recognition capabilities, have the potential to accurately assess freezing conditions on road surfaces without being influenced by light reflection or external factors. This development has the potential to make a significant contribution to the prevention of traffic accidents and the enhancement of driver safety.

Figure 1.Road Freezing (Black Ice)

2.2 LIDAR SENSOR

LiDAR sensor technology operates on the principle of remote detection utilizing light. It is a laser-based innovation that is capable of precisely measuring objects and distances within its surrounding environment. This capability renders it instrumental in identifying and analyzing the shape, position, and velocity of objects. The fundamental mechanism of LiDAR sensors involves the emission of high-frequency light signals from a laser source. Subsequently, the sensor measures the time taken for the laser signal to be reflected back after encountering an object. The distance to the object is calculated by determining the time of flight (ToF), which takes into account the speed of light and the direction of the laser emission. In this study, we present a methodology that employs this principle to generate three-dimensional coordinates. This methodology entails a series of processes that facilitate the real-time processing of high-resolution data, thereby enhancing the performance and efficiency of remote sensing technology across a range of industrial sectors.

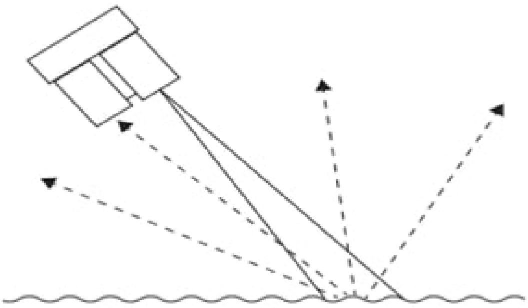

Figure2. Lidar Lite v3 Module

The reflection properties of an object's surface can be classified into three primary categories. In practice, however, it is not uncommon to observe a combination of several of these properties. These are referred to as diffuse reflection, specular reflection, and inverse reflection. The most pure form of a diffuse reflective surface is observed in textured materials, which uniformly disperse the reflected energy. As a consequence of this characteristic, a relatively predictable proportion of the dispersed laser energy is returned to the device. It can thus be concluded that the performance is enhanced. Table 1 Table 1 illustrates the discrepancy in the actual distance measurement as a function of the substance in question. The error rate is dependent on the actual distance and the substance in question.

Table 1: Table 1 shows the error rate of each actual distance and the result value measured by the Lidar Lite v3 Module [4].

Measurements Taken at 70°			
Substance	**Measurement distance [cm]**	**A real distance [cm]**	**Error rate [%]**
Ceramics	188.01	190	1.044
Tile	211.61	196	7.964

Wood	190.67	184	3.625
Concrete	166.56	171	2.556
Porcelain	183.83	184	0.092
Asphalt	168.49	170	0.888
Paving Stone	168.22	164	2.573
Grass	228.6	240	4.75
Cement	169.21	179	5.469
Sand	225.57	220	2.532

2.3 Lidar Lite v3 Module

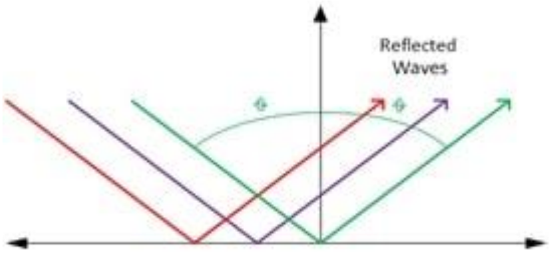

Figure3. Reflection of regular vibration waves on the surface

V = speed

f **= frequency**

λ = Wavelength

D = distance

T = time

$$V = f \times \lambda$$

(1) $$D = \frac{V \times T}{2}$$

Once the light sensitivity has been calibrated, a series of signals are transmitted in order to identify the peak size that occurs when the laser is reflected off an obstacle. The device then correlates the measured signals with the data records that have been previously collected. Upon completion of this process, some signals are transmitted for the purpose of quantifying the noise layer. This is achieved through the analysis of the correlation with previous signals. Subsequently, the change in signal magnitude transmitted by correlation analysis can be determined based on the received correlation record. This process is repeated until the peak exceeds the pre-established threshold, at which point the distance is calculated. Subsequently, the device generates an output signal that provides the distance, and the cycle is repeated. When reflection occurs, the characteristics of the transmitted wave remain unaltered, while the reflected waveform undergoes a change in direction, as illustrated in Fig. 1. Moreover, the speed, frequency, and wavelength are interrelated in accordance with the relationship depicted in Equation (1).

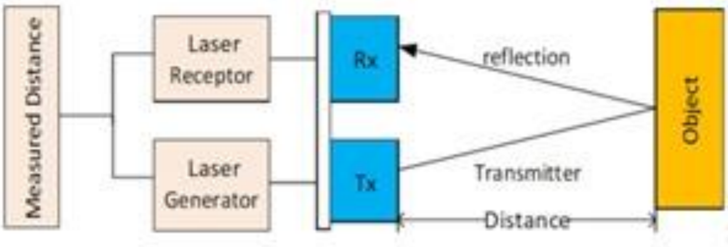

Figure 4: Lidar Lite v3 Module Sensor Operating Diagram

2.4 On-Device AI Edge Computing

The Lidar Lite v3 Module sensor, as illustrated in Fig. 4, is capable of detecting black ice. LIDAR can be employed to prevent the formation of black ice. By utilizing sensors to measure the surface and distance of the ground, the potential for the formation of black ice can be identified and addressed. At this juncture, the measured value is discerned by varying the temperature and angle, thereby facilitating an examination of the asphalt for the presence of black ice. LIDAR sensors are capable of collecting and analyzing laser data reflected from the ground, thereby obtaining information regarding the distance and height of the ground. Furthermore, this information can be utilized to estimate the glossiness of the ground and to leverage the characteristic of black ice, namely its tendency to reflect evenly, to ascertain the presence of black ice at a given point. The accuracy of the process can be enhanced by incorporating data on the ground's roughness.

3. RESEARCH RESULTS

3.1 Temperature Simulation Results

Table. 2 shows the simulation values as a table. It is a simulated value according to the temperature at which ice is generated.

Table 2: Difference from actual distance by temperature

Temperature[°C]	Asphalt[m]	Blackice[m]	Difference[m]
-4	1.668	1.637	0.051
-3	1.546	1.516	0.030
-2	1.648	1.618	0.030
-1	1.606	1.576	0.030
0	1.672	1.641	0.031
1	1.501	1.471	0.030
2	1.590	1.560	0.030
3	1.539	1.509	0.030
4	1.745	1.715	0.030

Figure 5 depicts the outcome of measuring the distance from minus 10 degrees to 10 degrees Celsius, with a particular emphasis on the freezing point of 0 degrees Celsius of ice. The distance was set to 1.60 m, and the measured angle value was fixed at 90°. The simulation was conducted assuming a thickness of 3 cm for the ice. The tables and graphs represent the resulting values.

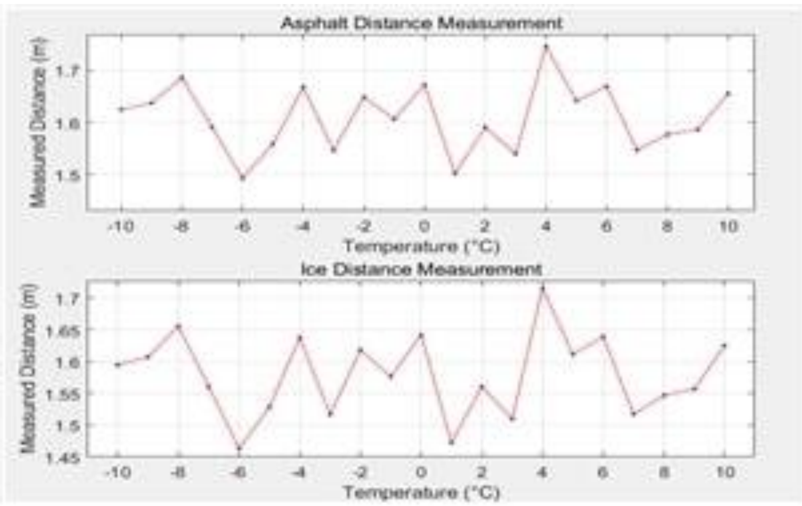

Figure 3: Graph of Actual Distance Comparison by Temperature

3.2 Angle Simulation Results

The distance measured by the sensor is calculated based on the time required for the D laser to initiate and complete its cycle, with the resulting angle designated as θ. Initially, the angle is transformed into radians.

Horizontal Distance = HD

HD = D ×cos(θ) (2)

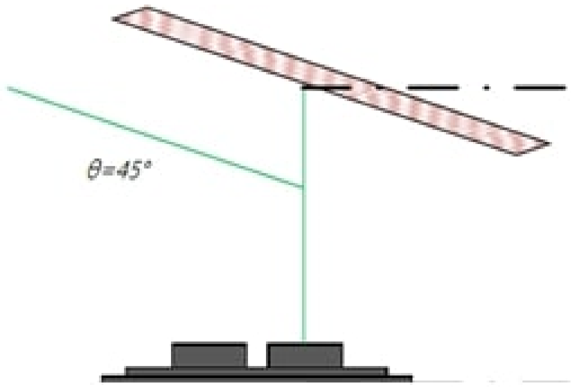

Figure6: Laser reflection trajectory at 45° angle

3.3 Compute processing performance comparison with penalty added

(2) The appropriate designation for this device is "lidar," in accordance with the established nomenclature. The horizontal distance to the target at the corresponding position may be calculated according to the distance value D, which is output from the desired angle by the sensor. The horizontal distance thus obtained is a value that takes into account the distance to the target according to the angle. In certain instances, the location of the black ice can be estimated with greater precision by measuring from multiple angles. Figure 6 depicts the simulated angle. The time was set at 1 p.m., and the temperature was set between minus 10°C and 10°C. The angle at which the lidar was measured on black ice was set between 0° and 90°. The simulation was conducted as follows and set to the same environment as the temperature simulation environment. The discrepancy in angle between asphalt and black ice was verified. The results of the temperature simulation demonstrated that the Lidar Lite v3 Module exhibited minimal sensitivity to temperature fluctuations. Consequently, it was determined that the module is well-suited for black ice detection. Consequently, despite the presence of an error, the precise value is attained due to its resemblance to the error rate referenced in the LiDAR sensor parameters.

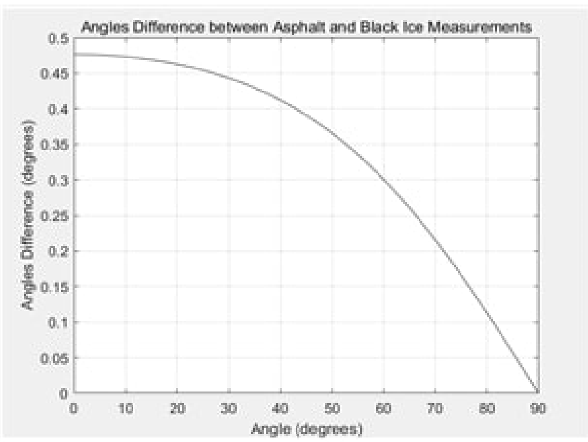

Figure 7: Angles Difference between Asphalt and Black ice Measurements

As illustrated in Fig. 7, the presence of black ice can be discerned by examining the discrepancy in the angular relationship between the asphalt and the black ice, as evidenced by the comparative analysis of the two graphs. The discrepancy is challenging to discern at the vertical angle; however, the divergence between the two datasets can be employed to examine the circumstances under which the angle ranges from 0° to 80°. Consequently, if the angular difference between asphalt and black ice is discernible within the specified angular range, the portion in question can be identified as black ice. This methodology thus allows for an increase in the accuracy of black ice detection.

4. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In this study, a LIDAR Lite v3 sensor was employed to simulate a methodology for the detection of black ice through the analysis of the difference in reflection between asphalt and black ice in accordance with temperature and angle. Consequently, the method of comparing the temperature between black ice and asphalt proved to have a limit in terms of successfully detecting black ice. However, in the simulation of black ice detection using the angle, a discrepancy was observed when comparing measurements taken at angles ranging from 0° to 90°. No significant difference was observed in the measured value in response to temperature changes when the sensor was employed. However, it was determined that black ice detection was feasible by leveraging the reflection angle in relation to the angle. Nevertheless, for this technique to be practically effective in detecting black ice, additional measures, such as the combined use of other sensors or altitude correction, are necessary. As the reliability of a single sensor is limited, further research is required to enhance the reliability and accuracy of black ice detection, with a particular focus on the utilization of complex sensors. These enhancements will facilitate the development of a more precise and secure black ice detection and management system in authentic settings.

5. ACKNOWLEDGEMENTS

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