Development of the System Architecture for Black Ice Detection to Prevent Transportation Calamities

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***Abstract*—The fast advancement of transportation technologies, particularly autonomous driving, has considerably decreased the occurrence of road accidents. However, one of the possible causes of traffic accidents in the age of autonomous driving is black ice, a thin coating of translucent ice on the road surface. This is particularly evident during Korea's winter season, when black ice can form owing to higher humidity, frequent fog, and hillshade. This paper presents an architectural concept of a black ice detection, prediction, and warning system to reduce vehicular catastrophes in order to build a more robust road management system by incorporating geolocation data into existing systems. The proposed architectural concept will be constructed using vision and audible sensors, as well as geolocation data, and will be combined with meteorological data to anticipate road surface temperature. Two mountainous locations with gathered meteorological data from 2022 to 2024 will serve as test beds for the proposed system.**

***Index Terms*—Autonomous driving, black ice detection, geolocation data, meteorological data, road management system.**

I. Introduction

Traffic accidents caused by snow and ice are quite prevalent in Korea during the winter when the average temperature is just 0.5°C. Black ice forms in Korea primarily because of the country's many mountains and sea-covered terrain. Black ice is a specific type of thin ice coating that forms on pavements and highways [1]. Wintertime fatalities are spurred on by black ice, which is extremely translucent and tricky to notice. Due to rapid temperature decreases, black ice habitually appears at night or early in the morning. Considering how elevated and exposed bridges and overpasses are, this phenomenon is especially apparent there [2]. As winter weather becomes milder, black ice becomes increasingly important. The Korea Transport Institute reports that when the temperature in winter is above 2 to 3 C, the mortality percentage of driving crashes related to black ice is highest, at 4.2%, and is lowest, at 0.7%, when the temperature is around minus 1 and 0°C. This is owing to the fact that the increased water vapor brought on by the higher air vapor owing to the higher air temperatures and the cold road surface may combine and form black ice [3].

As the population in mountainous areas has grown recently, many roads are being restored, and new highways and tunnels are being built, which will boost driving speeds. However, due to increased humidity and temperature fluctuations, mountainous parts of Korea, particularly those near the sea, are more prone to having black ice [4]. The majority are found in moist, cold regions like the bridge, the hillside shaded by the trees, before and after passing through the tunnel, etc. In regions where there is often a lot of moisture, black ice is produced when the temperature drops quickly, which raises the likelihood of traffic accidents. Despite the fact that government efforts have reduced highway accidents, wintertime black ice incidents are continuously rising. This has led to a growing demand for research on black ice prediction, detection, and warning systems.

II. Overview of the Architecture

This section discusses the broad concept of creating an incident prevention management system for situations involving black ice. Fig. 1 illustrates the general architectural concept of the system for preventing events based on black ice. During the course of this project, a black ice detection system will be integrated with the road monitoring equipment already in use. Black ice often forms throughout the winter under special circumstances in very specific places. As a result, the black ice detection system is made up of certain integrated devices that are only employed during a given season (about November to February), while other seasons have the characteristics of performing a different function. Additionally, in order to maximize efficiency, it is planned to create an integrated road monitoring system that, by combining with already-existing road monitoring equipment, may identify black ice during a particular season while still performing regular road monitoring functions. The embedded road monitoring scheme will also construct an integrated data control unit that can coordinate data collection (video, detection information, environmental details, etc.) and maintain surveillance systems (road condition surveillance, crime prevention, illegal parking, etc.) on roads at the same time.

A. Characteristics of Development Output Installation Areas

The regional features of the Jeju area, where the black ice detection system created under this project will be placed, include thick sea fog and hilly terrain without tunnels. These

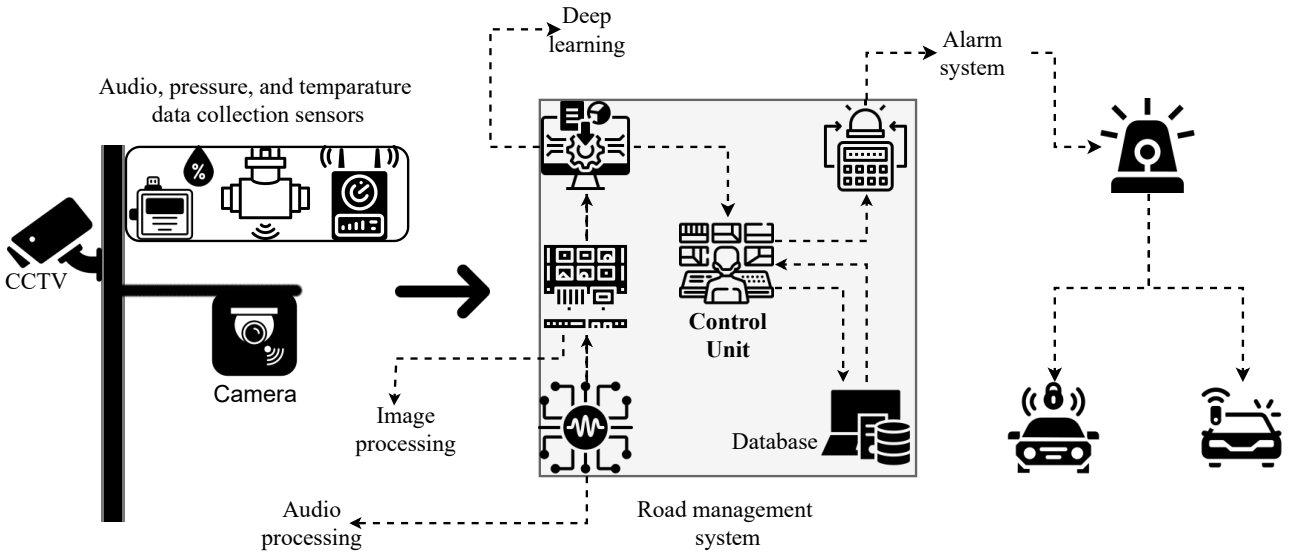

Fig. 1. Architectural concept of black ice based incidents prevention management system

qualities include dense marine fog, which constantly causes freezing on the road owing to a large influx of moisture and necessitates driver attention. A specific detecting system is needed for the northern region, which is particularly sensitive, and the southern side, which is in the effect of cold sea breezes and sea fog in the Jeju area, since the majority of the area is near to the mountain area but lacks a tunnel. Therefore, it is essential to develop performance in this work while taking Jeju's environmental conditions into account. Both of these sides will be outfitted with installation equipment to gather video and audio data from infrared cameras, closed-circuit television, and sound sensors. Since nighttime has a darker impact on CCTV cameras, the IR camera will enable the capture of data throughout the night, often when black ice will emerge. Additionally, the sound sensors will record the sounds produced by the vehicles as they pass by on the highways. Input for an image-based deep learning model will be taken from the videos in the form of images, and input for an acoustic-based deep learning model will be taken from the sound data. In this project, the development of black ice prediction methods employing Long Short-Term Memory (LSTM) and Recurrent Neural Networks (RNN) methods utilized in weather forecast systems is taken into consideration. Since LSTM outperforms other RNN models for prediction [5], the goal is to provide effective outcomes by combining LSTM with RNN models and a convolutional neural network (CNN) model for black ice detection method.

III. Conclusion and Future Work

This paper provides an overview of the black ice detection, prediction, and warning system architecture to prevent winter-time vehicle accidents. The architectural design will integrate vision and acoustic-based data along with the sensor data to detect black ice, distinguish it from conventional snow, and predict the black ice appearing period in winter time. The development output installation areas will be considered in Jeju Island in two different mountainous regions to collect data along with the Kumoh National University campus from 2022 to 2024. Although it would require a significant discussion to go through the complete process from data collection to pre-processing to warning alert management, this will be covered in a forthcoming article, allowing this one to focus solely on architectural design concepts. The following article will go into the data collection technique, covering the collection of data from acoustic sensors and infrared cameras (IR), as well as how the two independent datasets may be used to detect black ice.

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References

[1] T. Liu, Q. Pan, J. Sanchez, S. Sun, N. Wang, and H. Yu, "Prototype decision support system for black ice detection and road closure control," *IEEE Intelligent Transportation Systems Magazine*, vol. 9, no. 2, pp. 91–102, 2017.

[2] T. Liu, N. Wang, H. Yu, J. Basara, Y. Hong, S. Bukkapatnam *et al.*, "Black ice detection and road closure control system for oklahoma." Oklahoma. Dept. of Transportation. Planning and Research Division, Tech. Rep., 2014.

[3] S. Kim, Y. Jang, S. Kim, D. Min, H. Na, and J. Choi, "A study on the effects of factors of traffic accidents caused by frozen urban road surfaces in the winter," *International Journal of Highway Engineering*, vol. 17, no. 2, pp. 79–87, 2015.

[4] J.-K. Lee, Y. Huh, and J. Park, "Geospatial simulation system of mountain area black ice accidents," *Applied Sciences*, vol. 12, no. 11, p. 5709, 2022.

[5] M. Golam, R. Akter, J.-M. Lee, and D.-S. Kim, "A long short-term memory-based solar irradiance prediction scheme using meteorological data," *IEEE Geoscience and Remote Sensing Letters*, vol. 19, pp. 1–5, 2021.