Black Ice Prediction and Prevention Alarm System

Gul-Won Bang, Yong-Ho Kim

Abstract. The system which is able to not only predict road freezing condition in advance and but also inform that is proposed in this study. The composed hardware to measure weather are microprocessor, temperature sensor, humidity sensor, atmospheric pressure sensor, precipitation sensor, LTE modem, solar cell panel and its controller, and battery. In addition to, there are software for forecasting freezing located in a specific area where devices to detect data such as temperature, humidity, atmospheric pressure, and road temperature are installed for the purpose of not only transmitting their data but also data storage through wireless internet modem. Real-time monitoring and an algorithm for forecasting freezing make it possible to predict freezing by utilizing the accumulated data. Freezing on road can be occurred according to bigger humidity, big difference of humidity as well as of atmospheric pressure. The measurement of atmospheric temperature as well as road temperature, atmospheric pressure and humidity is conducted by the proposed system in this study. The relationship between a changing weather data in the past winter seasons during from 15th November to 31th March and the amount of precipitation included a snowfall is grasped to digitize. Present weather information is applied by not only detecting the phenomenon to show changing at constant humidity, atmospheric pressure, and temperature but also calculating a precipitation probability in case of this reiteration phenomenon or particularly higher humidity as well as particularly lower atmospheric pressure to grasp of relations with precipitation. The proposed system is composed up four steps such as good, concern, caution, and warning through forecasting freezing time from 3 hours ago. Therefore, it is possible not only to forecast freezing hazard up to 70% due to frozen rain but also to use snow-removing work prepared in advance as well as weather information aids by forecasting freezing.

Keywords: freezing rain , Traffic Accident, Prevention system, road surface, weather, weather station

I. INTRODUCTION

According to advanced weather forecast techniques the Met Office weather forecast service is increasingly developed. Sector scale forecasting is ultimately necessary to a partial forecast for driving. The area forecast that is composed of sector forecast is necessary to road driving but the weather forecast of small local roads is still unsatisfied.

Special weather section such as the surroundings of dams and rivers, bridges through a valley penetration, roads which are separated by mountains with east and west or south and north direction can be considered as a weather forecasting vulnerable area. These areas may happen some other weather condition that are differ from weather forecast service due to difficult predictions of road condition in these areas. Therefore special managements of these areas are necessary to prevent large scale accidents[1] [3] [4].

An ice road in the winter season cause traffic accidents or traffic problems. There were 150,000 cases of traffic accidents in the winter season from 2008 to 2010 according to the analysis of Hong Hyungi in Seoul City University. The road condition amongst them with snow covered road or freezing condition was 7%. Traffic accidents due to icy roads have 1.6 times higher lethality than similar snow-strewn roads. It is very difficult to recognize black icy roads for drivers compared to snow-strewn roads. Comparing to other roads condition an icy roads have the lowest coefficient of friction as well as long braking distance. That makes not only traffic accidents increased frequently but also a large number of traffic-related deaths increased[1].

Many accidents occurred on bridges happen according to the type of roads because the probability of falling is increased due to a lower temperature than regular roads. The possibility of pedestrians' falling on icy roads will be increased because it makes the road slippery and transparent when freezing drops of rain is frozen. In 16th December 2012, Seoul Korea, the city had frozen hard due to freezing rains, 360 falling accidents were reported in just one day. Driving on the frozen road caused by freezing rain is a disaster for drivers because it is differ from driving on icy roads. Drivers don't speed on icy roads because they already know the icy condition of road. Rain is frozen on an asphalt road the instant that freezing drops of rain is raining. It can cause a big problem for drivers because it looks like no ice with a black color of road even though the asphalt road has already covered with an ice. This phenomenon is called a black ice that is likely to increase the occurrence of big accident. These kinds of accidents tend to accompany serious damage and casualties. There were four major bump accidents a multi-car collision in 2008, 2009, 2012 in Korea. The all accidents have believed an estimated freezing rain. The characteristic of accidents has occurred on the road between a bridge pier and a vicinity of tunnel as well as valley during winter times between 8 and 9 in the morning when the temperature is the lowest[2].

Many studies have been done on the forming of freezing rain and many efforts are also conducted to

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prevent it. But there is no device to exactly predict freezing rain on roads even the most sophisticated device known as ROSA made by the one of Finland companies can't do it because it is impossible to predict freezing rain due to weather data measured in the ground. One of the effective causes for generative principle of freezing rain is known as the standard atmospheric pressure at a point of 850HP and the temperature as well as humidity and a rainfall probability at a height of 1.5km must be combine together. The development of product that is applicable to road management and the study of algorithm that performs the prediction probability of freezing with more than 70 percent is implemented in this study.

II. RELATED WORK

2.1 freezing rain

Freezing rain is known as icing rain that falls as a liquid but freezes into glaze upon contact with ground or airplane surface in flight. The characteristic of freezing rain makes ice sheet homogeneous, smooth, and transparent. It snows at low temperature in the atmosphere while descending snow is changing into rain. This rain is supposed to freeze when it contacts with subzero subjects around the ground. So it is called freezing rain capable of being frozen.

In order to make freezing rain the temperature of ground or subject surface must be below zero. But freezing rain can be made due to super-cooling raindrop even though the temperature in the atmosphere is above zero. It is a good example that clear icing is occurred when an airplane flies in the super-cooling water layer. Freezing rain is occurred frequently where there are protruding branches of trees or signal lights in the atmosphere because their heat loss are larger than the ground surface. The area having frequent freezing rain is the place where it is occurred cooling easily. Basin like area that is wholly or partly surrounded by higher land or mountain and bridge is the place where freezing rain is occurred[2] [5] [6].

2.2 Occurring condition of freezing rain

The below picture shows the type of precipitation according to the structure of atmosphere. The black solid line in the picture shows zero degree. If air is located in the left side of this line it means below zero zone. Also it means above zero zone if air is located in the right side of the line. The blue line is a temperature in the atmosphere showing a temperature condition of air ranging from the ground surface to the upper atmosphere.

The temperature line in the atmosphere from the ground to the upper is all positioned below zero zone in the first right side of picture. It has snow in this case. The second right picture shows snow grains. It rains in the middle of atmosphere with above zero temperature while the temperature is descending below zero near the ground surface. Therefore snow grains is forming instead of snow. The third right picture shows that freezing rain is raining. It looks like snow grains but the altitude of above subzero is larger to near the ground. Even though there is a below zero layer near the ground surface the thickness is not large. Raindrop fallen to the ground is not frozen where the temperature of ground surface is subzero. So raindrop to the ground is frozen instantly. The last left picture shows that it rains due to above zero temperature from the ground to the upper atmosphere[2] [7] [8].

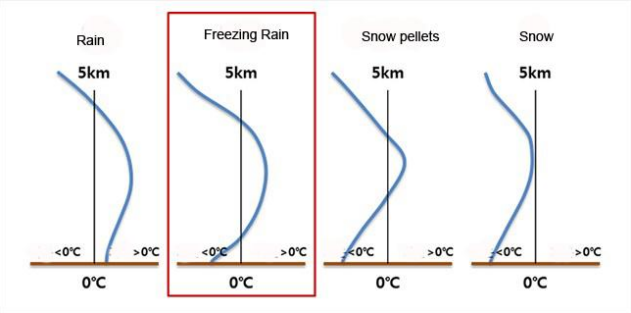

Fig. 1 Condition for forming of freezing rain

2.3 Freezing Rain Occurrence area

Freezing rain is mostly occurred in the northern side of a warm front on the ground. A warm front in the northern hemisphere is located in the east side of low atmospheric pressure. Warm air located in the upper side of a warm front is shown in Figure 2 while cold air in the lower side of it is stayed according to a frontal surface. A surface of discontinuity between two different airs exists and it becomes a warm front. It rains from a frontal surface that is reached near a ground to 200km ahead because an ascending warm air creates rain clouds.

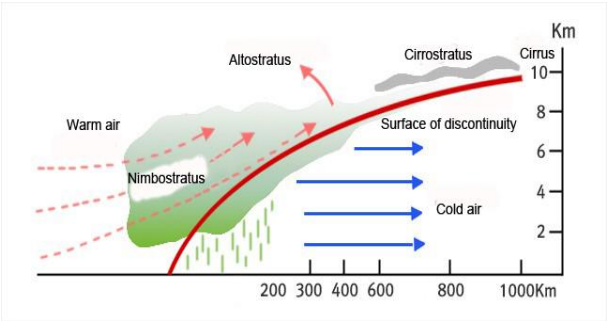

Fig. 2 Structure of warm front

An ice accretion on a warm front is shown in Figure 3. It snows and rains in the front of a warm front and it snows in the upper atmosphere where the temperature is below zero while it's sleeting or freezing rains at the place above freezing like in Figure. Snow in the upper atmosphere falls to a warm layer near 500~900m near the surface of the earth to start melting. Melted and super cooled drops of rain had fallen onto the ground and the form of snow pellets drops in front colder place. Melted and super cooled drops of rain in the back side of snow pellets are instantly frozen as soon as they touch the ground. This is called freezing rain and its principle is like super cooling phenomena that liquid is not freezing even though temperature is in below the freezing point. The instant that rain impacts the ground, it occurs freezing in a moment[2][9][10].

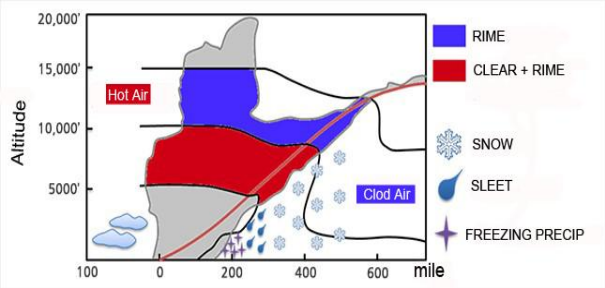

Fig. 3 Region of freezing rain in warm front

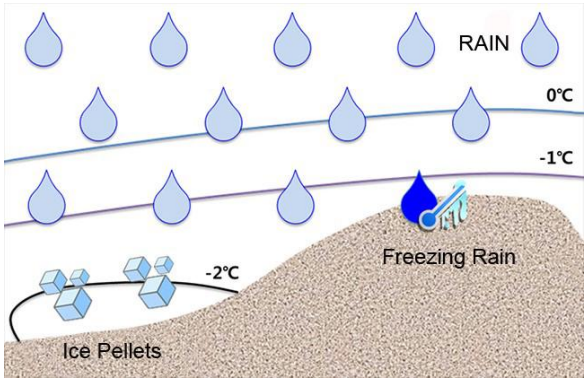

Fig. 4 Distribution of ice and freezing according to altitude

2.4 Occurrence of freezing rain and prediction

There were not many researches and weather forecast in the freezing rains in Korea. According to the paper "The characteristics of time-domain distribution and occurrence in the freezing rains", the analysis of observed freezing rains at the point of thirty eight areas during from 1904 to 2012 has reported. Two times in a day occurred a freezing rain was 193 days among 589 days which occurred freezing rains according to the analysis. Ulleungdo island was reported the most freezing rain area that recorded 61.97 percent in the whole occurrence days. It means an average forty eight days per ten years while other areas except Ulleungdo island recorded an average 1.13 days per 10 years. A look at the statistics of each area reveals that the area of east coast in duration time of the rain was longer than other coastal areas while the area of south coast was relatively low. The duration time in case of rain from one minute to thirty minutes was the highest as 62.7 percent because there were many cases changing from freezing rain to snow and changed to freezing rain again. There was a case that lasted a long period more than six hours. But it was a very rare case as 0.9 percent of whole occurrence. When is the time to make the most freezing rain for a day? Early morning when the temperature in north of precipitation zone of warm front drops down at lowest and becomes stable. This is when the front passed, The probability of occurring freezing rain is much more higher.

Prediction reference for freezing rain based on statistics by regional groups in the US has been created and utilized to prevent from harm damage caused by freezing rain. Forecast of freezing rain is provided by probability forecast. There are an existing prediction method such as model usage, radar measurement, division method for thickness distribution. Model usage is based on the vertical thermodynamic profile and rainfalls per hour. Weather algorithm model Baldwin is used now to predict the type of precipitation. Radar is used to detect the created bright band when the snow is starting to melt at around 500~900m from ground level. Division method for thickness distribution is to divide thickness between 700~850hpa and 850~1000hpa for forecast. An accurate forecast of freezing rain has a long way to go. National Weather Service in the US forecasts the probability because it is hard to predict the accurate amount of freezing rain while Korea can't predict it[11][12][13].

III. BLACK ICE PREDICTION

3.1 Understanding and digitizing the relations between weather data in the past winter season (15th December ~ 31th March) and precipitation

A phenomenon which shows the abnormality of changing rate against humidity, atmospheric pressure and temperature is detected, and the relations with precipitation in case of reiteration of the above mentioned phenomenon, particularly high humidity and low atmospheric pressure are grasped to digitize it for calculation of precipitation probability. A certain area of weather data is sampled and is digitized. According to the analysis of weather data in a certain area as well as of precipitation probability, the probability of precipitation is showed the increase proportionally to big difference in humidity, higher humidity, lower atmospheric pressure, and big difference in temperature.[14]

3.2 Humidity difference between present humidity and that of one hour ago and analysis of precipitation probability based on present humidity

The more the humidity is high and its difference is big, the more high precipitation represents. Total target time when the humidity is more than 30 percent in case of humidity difference with ten percent is 3,068 hours. Precipitation rate is 9.58 percent when its duration time was 294 hours. Probability of precipitation is shown in Table 1 according to humidity difference.[15]

Table 1. If the humidity difference of 10%

Humidity	Chance of Rain
30%	09.58%
40%	09.91%
50%	11.00%
60%	13.72%
70%	18.00%
80%	20.29%
90%	22.61%

3.3. Analysis of precipitation probability according to humidity difference between the present humidity and that of one hour ago and atmospheric pressure

A humidity difference (between the present humidity and

that of one hour ago) and a temperature difference (between the present temperature and that of one hour ago) according to atmospheric pressure by time

The more the difference of temperature and humidity is high, the more high precipitation represents according to the analysis result of precipitation rate.

Table 2. If the humidity difference of 10%

Atmospheric pressure	Chance of Rain
1000hp	100%
1005hp	75%
1010hp	36.36%
1015hp	31.29%
1020hp	21.63%
1025hp	20.29%
1030hp	10.39%
1035hp	09.66%

3.4 Analysis of precipitation probability based on daily time period according to humidity difference between the present humidity and that of one hour ago and difference between the present temperature and that of one hour ago

A humidity difference (between the present humidity and that of one hour ago) and a temperature difference (between the present temperature and that of one hour ago) according to atmospheric pressure by time

The more the difference of temperature and humidity is high, the more high precipitation represents according to the analysis result of precipitation rate.

Table 3. If the humidity difference of 10%

Temperature difference	Chance of Rain
-0.2°C	29.47%
-0.4°C	32.47%
-0.6°C	38.14%
-0.8°C	42.57%
-1.0°C	44.17%
-1.2°C	53.19%
-1.4°C	57.14%
-1.6°C	57.58%
-1.8°C	58.70%
-2.0°C	71.43%

3.5 Calculation formula for probability of precipitation

$$HS = NH = HAH \quad (1)$$

$$HAS = HS + NA \quad (2)$$

$$HSAS = HS - AS \quad (3)$$

$$AS = NA - HAA \quad (4)$$

$$ASH = AS + NH \quad (5)$$

$$ASNS = AS + NA \quad (6)$$

HS is calculated by difference of humidity in formula(1), and NH is present humidity while HAH is that of one hour ago. HAS is a humidity difference plus present atmospheric pressure due to the relations between humidity difference(HS) and atmospheric pressure in formula(2). HSAS is humidity difference minus atmospheric pressure as formula to find humidity difference(HS)and atmospheric pressure(AS) in formula(3). Atmospheric pressure(AS) in formula(4) is calculated by the value that present atmospheric pressure minus atmospheric pressure in one hour ago. Relation formula between the difference of atmospheric pressure and humidity(ASH) is formula(5) and ASH is the difference of atmospheric pressure plus humidity value. Relation formula between the difference of atmospheric pressure(AS) and present atmospheric pressure(NA) is formula(6) and ASH is the difference of atmospheric pressure plus present atmospheric pressure. Lower temperature between two is selected and the probability of precipitation is 100 percent when humidity difference(HS) is more than 10 and present humidity(NH) is more than 80 percent or temperature is descending while humidity is ascending.

Actual humidity value measured is describe at a graph in Figures 5. It is a correction conducted value against an actual value and probability of precipitation according to humidity difference and the present humidity is described at a graph in Figure 6.

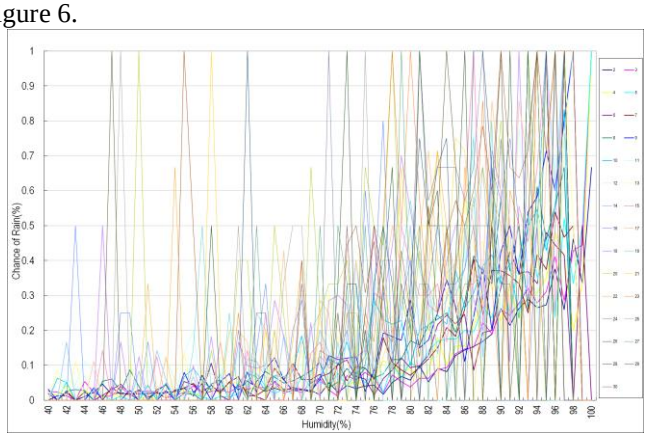

Fig. 5 Precipitation rate according to humidity difference between the present humidity and that of one hour ago and the present humidity(field data with within three hours).

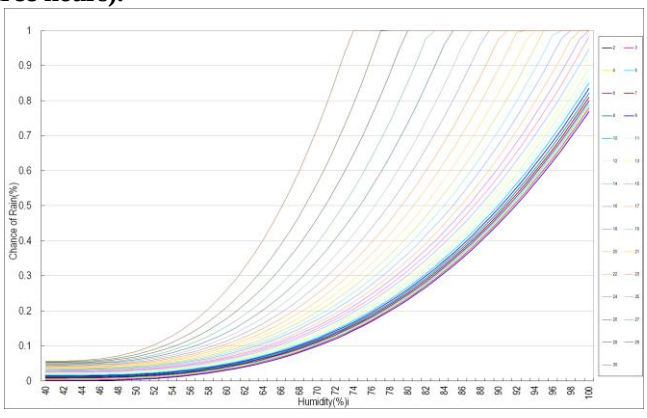

Fig. 6 Precipitation rate according to humidity difference just before measurement between the present humidity and that of one hour ago and the present humidity(correction data with within three hours).

Actual value of humidity and atmospheric pressure measured is describe at a graph in Figures 7. It is a correction conducted value against an actual value and

probability of precipitation according to humidity difference and atmospheric pressure is described at a graph in Figure 8.

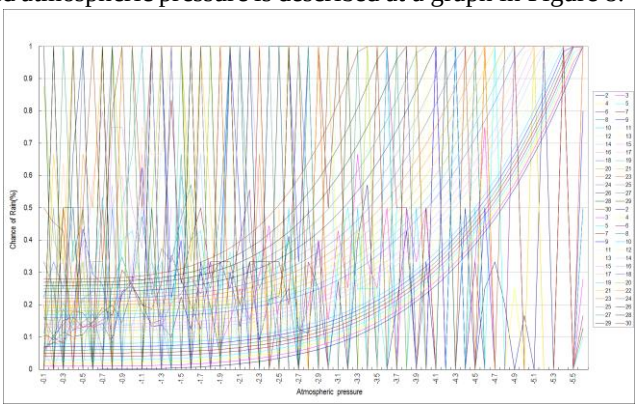

Fig.7 Precipitation probability according to humidity difference between the present humidity and that of one hour ago and atmospheric pressure difference between the present atmospheric pressure and that of one hour ago(field data with within three hours).

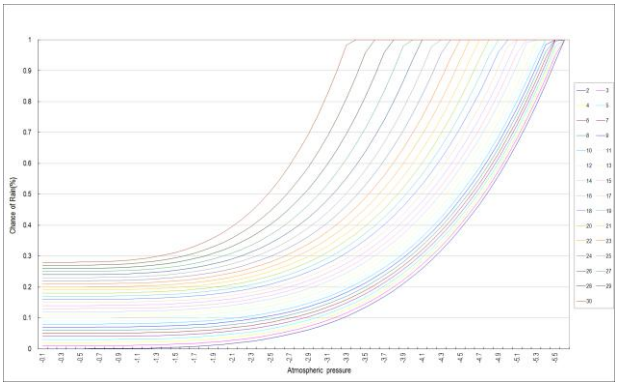

Fig. 8 Precipitation probability according to humidity difference between the present humidity and that of one hour ago and atmospheric pressure difference between the present atmospheric pressure and that of one hour ago (correction data with within three hours).

IV. SIMULATIONS

4.1 Weather station

Weather station is composed of temperature sensors to measure temperature and road temperature, humidity sensor, atmospheric pressure sensor, precipitation sensor, data processor to deal with data between sensors, solar cell panel to supply power, solar cell controller, battery, and wireless transmitting device to send data. Data processor replaces existing data logger with arduino. LTE modem as a wireless transmitter is applied to make it possible to communicate where there is no internet on road and mountain regions. Measurement sensor for road temperature is designed to expand cross-section area for the purpose of reducing error existed in real road temperature.

4.2 Weather station installation

Temperature sensor is buried in a road verge and weather station is installed in outer road to gather weather data such as atmospheric temperature, humidity, atmospheric pressure, precipitation, and sensing precipitation. Solar cell panel for constant power supply is installed. Application of weather data from sites of disclosing weather information such as weather center, Google and Naver makes it possible not only to predict weather on roads but also to generate combined information through measurement of road temperature but also to forecast freezing rain based on the real-time temperature data at an altitude of 1.5km from weather center. Weather station for weather measuring on road is installed on road to measure temperature, road temperature, humidity, and atmospheric pressure with ten minutes' intervals and to transmit measured data to server through wireless mobile internet network. The transferred data is store in the server database to use the reference for freezing prediction system.

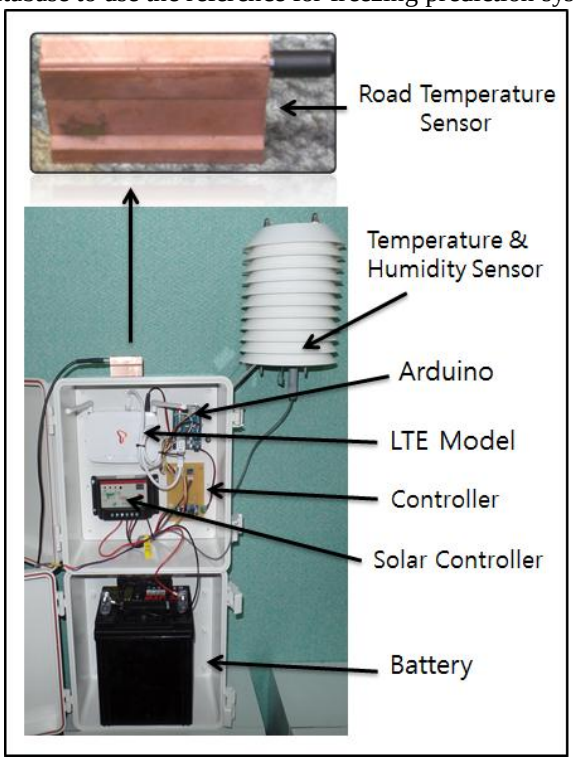

Fig. 9 Weather station

4.3 Black Ice Prevetoin System

4.3.1 Web based monitoring system of freezing notice

Web program such as bipa and php is developed to monitor in real time through internet web site. Web design is shown in Figure 10. to develop web program for freezing notice with graph features for road temperature in each hours, atmospheric temperature, humidity, and time. Bold lettering and more bigger mark can be displayed at lower temperature between road temperature and atmospheric temperature. Prediction algorithm for freezing is applied to forecast four steps such as good, concern, caution, and warning. Prediction system for freezing which is actually operated in PC is shown in Figure 11.

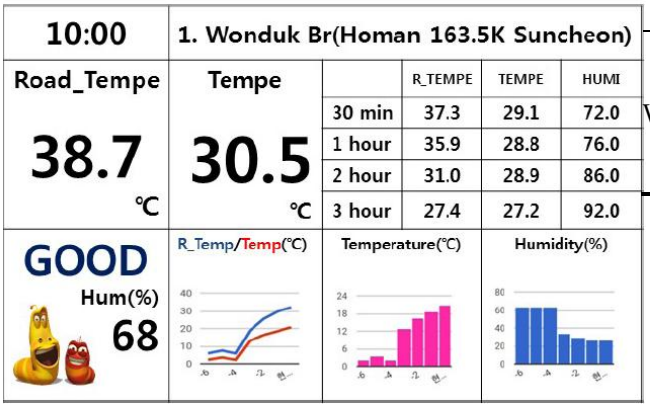

Fig. 10 Design of web screen

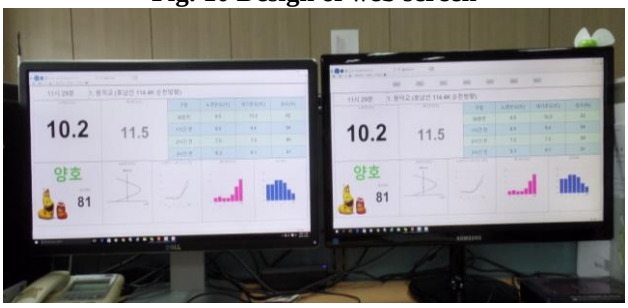

Fig. 11 Implemented screen for manager

4.3.2 App based monitoring system of freezing notice

Mobile web that is able to monitor freezing prediction system in real time anywhere is developed. Freezing. The prediction system which is operated in mobile device is shown in Figure 12 and it is possible not only to inform weather data and freezing condition in the point but also to mark the point that is installed multiple locations on the road from No.1 to No.7

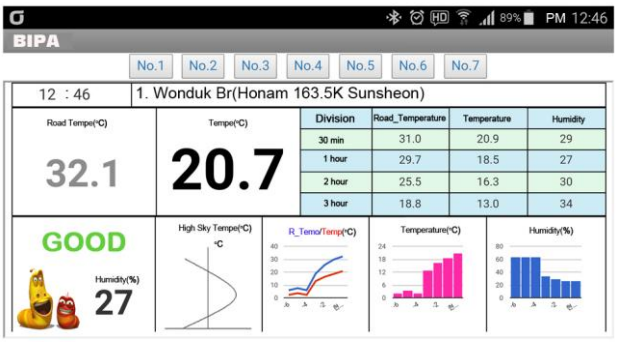

Fig. 12 Mobile app screen(BIPA.apk)

V. CONCLUSION

Table 4. Status Notification

Alarm	Weather conditions
Good	Road surface temperature or temperature over 6 degree
Attention	Precipitation ratio is more than 37.2% in the temperature range between over 3℃ and below 6℃. Precipitation ratio is above 60% in the humidity ascendant.
Caution	Precipitation ratio is more than 60% in the temperature range between over 1℃ and below 3℃. More than 60% in case of humidity in the ascendant. More than 60% in case of temperature in the descendant
Warning	Precipitation ratio is more than 37.2% in the temperature range within 1℃. More than 60% in case of humidity in the ascendant. More than 60% in case of temperature in the descendant.

Poor section in road the decision of preventive snow-removing work is difficult due to not only inconsistency of snow-removing work but also difficulty of weather information gathering at poor section of road because a person in charge for situation judges the work subjectively in case of the snow-removing work at poor section of road. It can't quickly meet the occurrence of freezing rain due to the difference between the real situation in road and the weather forecast because of physiographic feature. There is also disadvantage such as the difference between the road temperature and atmosphere temperature, temperature information gathering in real time and a large range of error in ±2~3℃ in case of measuring road temperature with infrared thermometer. The prediction algorithm of freezing is developed to improve the reliability of freezing forecasting in this study based on the analysis of accumulated data during twenty years as well as gathering a real-time weather information at poor section of road.

Prediction algorithm for freezing based on analysis of accumulated data is developed to increase reliability for prediction of freezing. Building of the prediction system for freezing makes it possible not only to take a measure weather information for the poor section of roads but also to provide fast snow-moving work.

Freezing forecast system utilized the application of customized weather information analysis has a feature of accurate data accumulation by securing the preciseness of road temperature through a continuous correction work such as prevention for icy road as well as for accident according to preparing preemptive snow-removing work based. The on providing a customized weather information through the sharing a weather information with weather center. The development of mobile application makes it possible not only to manage an effective road management for providing management officer with a real-time weather information at the spot but also to build a comprehensive management system of snow-removing work with the connection of freezing forecast system. The based on data that a cruising patrol car which is installed information gathering device is automatically collected an atmosphere temperature as well as road temperature, humidity, and road condition.

This system provides the foundation of smart maintenance management through a salt water spray equipment, snowplow, patrol car, snow-removing related equipment and linked IoT(Internet of Things). The study of warning system for icy road from fog is anticipated based on the analysis of correlation for humidity and temperature according to collected data henceforth. The visualization of meteorological changes can make judging the situation

with speediness and correctness possible to protect traffic accidents.

ACKNOWLEDGMENT

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