

# **The Application of Visible Image Road Surface Sensors to Winter Road Management**

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## **Abstract**

Accurate grasp of road surface conditions is essential to winter road surface management. Road administrator is monitoring the conditions by road patrols and partly by using closed circuit television (CCTV) cameras and sensors. However, continuous monitoring with CCTV cameras is hard from the perspective of workload, and low judgment performance.

The visible image road surface sensor developed by the Advanced Cruise-Assist Highway System Research Association (AHSRA) and the National Institute for Land and Infrastructure Management therefore has considerable potential for use in road surface management, enabling both the effective utilization of existing infrastructure such as CCTV cameras and the detailed monitoring of road surface conditions.

Early detection of road surface freezing and refreezing after the application of freeze inhibitors are extremely important in preventing road surface from being frozen.

The authors therefore introduced methods of using visible image road surface sensors to enable early detection of these phenomena.

## Background

Accurate understanding of road surface conditions is essential to effective and efficient implementation of road surface management in winter (clearing snow, applying freeze inhibitors, etc.). However, road surface conditions vary significantly according to weather, terrain, road structure and traffic volume, among other factors.

Judgments are therefore often based on experience, utilizing information gained from operators and contractors traveling the roads, and data from weather monitoring devices such as CCTV cameras. This leads to the issue of how this knowledge and experience should be passed on to new personnel. In addition, past data must be evaluated to verify the effectiveness of road surface management. However, work data collected based on experiential values includes error according to the scope of these values, and it is very difficult to statistically verify the data.

For these reasons, the efficient implementation of road surface management requires the introduction of a system to assist in accurately judging road surface conditions.

In addition, as CCTV cameras have become cheaper, and large numbers have been set up on roads for use in road management, it was necessary to make more effective use of these cameras rather than simply using them for monitoring.

There is therefore considerable potential for the use of visible image road surface sensors enabling accurate judgment of road surface conditions from CCTV images.

### Visible Image Road Surface Sensors

The visible image road surface sensor was developed as an R&D project for the Advanced Cruise-assist Highway System (AHS). It enables road surface conditions (dry, wet, water film, accumulated snow, or ice) to be judged by applying image processing to images from CCTV cameras.

When the sensors are first introduced, a database of specific characteristics associated with different road surface conditions will be created. Road surface conditions will be judged by searching for the set of specific characteristics in the database closest to those in the image from the CCTV cameras.

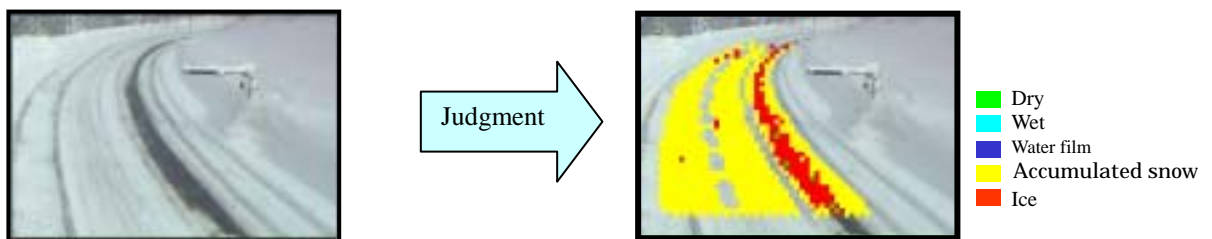


Fig. 1 Judgment of Road Surface Conditions

Despite the fact that the system was developed as an element technology of the AHS, because the sensor will enable infrastructure such as CCTV cameras to be effectively utilized and enable detailed judgment of road surface conditions, its employment in road management work is highly anticipated.

**Increasing Efficiency of Winter Road Management**

The visible image road surface sensors break up the images recorded by CCTV cameras into smaller units, and are able to output road surface condition information for each of these unit images.

This will enable operators to make more thorough judgments on where to conduct road management work and to formulate more effective work plans. In addition, the ability to judge, for example, the percentage of snow cover or the percentage of freezing using sensor output will enable road surface conditions to be judged on the basis of a uniform standard. In addition, operators will be possible to evaluate the work timing and the work projects, if operators compare the actual road management work with records that are past judgment by visible image road surface sensors, the images these judgments were based on, and road surface temperatures. Therefore operators will be possible to establish more effective and efficient road management plans.

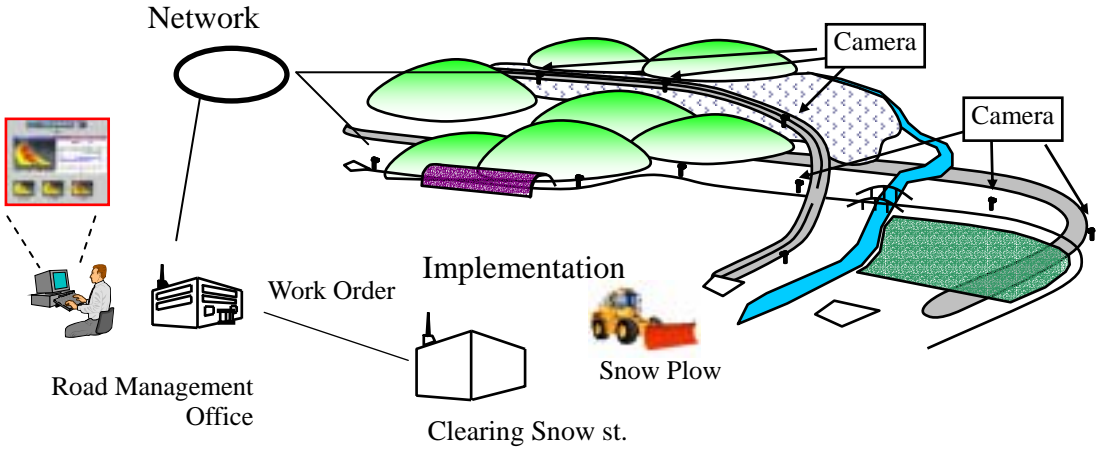


Fig. 2 Winter Road Surface Management using Visible Image Road Surface Sensors

**Problems of Winter Road Management**

Early detection of the commencement of freezing of a road surface and the application of freezing inhibitors is an extremely important part of winter road management work. Conventionally, freezing inhibitors have been applied after detecting freezing of road surface by a patrol or by means of images from a CCTV camera. Early detection of freezing requires

constant monitoring of road surface, but this is costly and entails a significant workload. We therefore studied the use of visible image road surface sensors for early detection of freezing. Detection of refreezing following application of freezing inhibitors is also extremely important. Currently, patrols are used to detect refreezing. However, the limited number of patrols and the complexity of the process of refreezing make accurate detection difficult. We therefore studied the process of refreezing and the use of visible image road surface sensors to detect refreezing.

### Early Detection of Freezing

Freeze inhibitors can be applied either before or after road surface freezes. It is preferable to apply the freeze inhibitor before freezing occurs, but to do so, it is essential to be able to identify the signs of the process of beginning to freezing.

The use of visual image road surface sensors enables continuous monitoring of road surface conditions. In addition, the monitoring terminal for the sensors outputs time history data for detection results, road surface temperature and changes in atmospheric temperature in the form of graphs (see Fig. 3), enabling monitoring personnel to refer to past records of these parameters, and therefore to be aware to some extent of the signs of freezing.

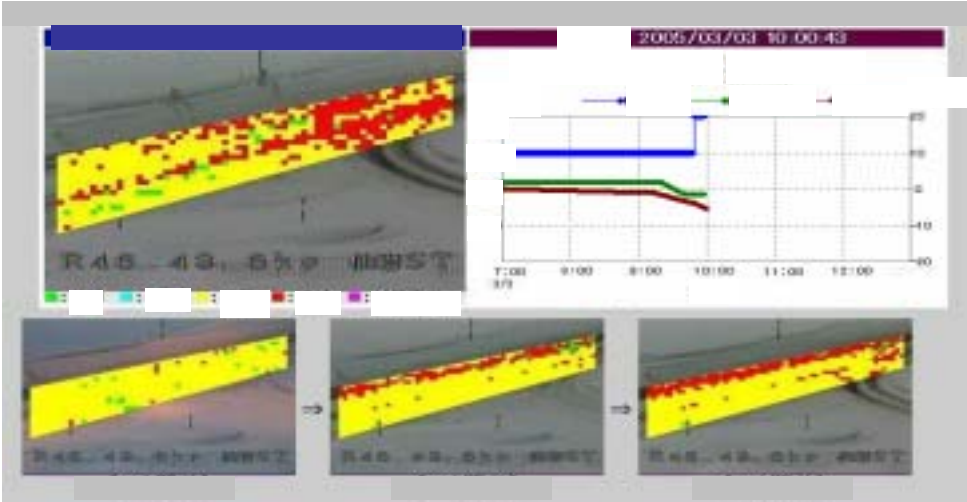


Fig. 3 Detection Results, Road Surface Temperature, and Changes in Atmospheric Temperature

The changes in detection results are output as graphs by the monitoring terminal, as shown in Fig. 3. The changes in the graphs show operators the extent of the phenomena and the direction in which the phenomena is moving. The graphs in Fig. 3 show a surface condition changed from snow-covered to ice.

In addition, when specific phenomena that have been programmed in advance into the monitoring terminal occur, operators are notified by E-mail and pop-up displays. This means that operators can be aware of changes in phenomena without continuous monitoring the screen, thus reducing their workload.

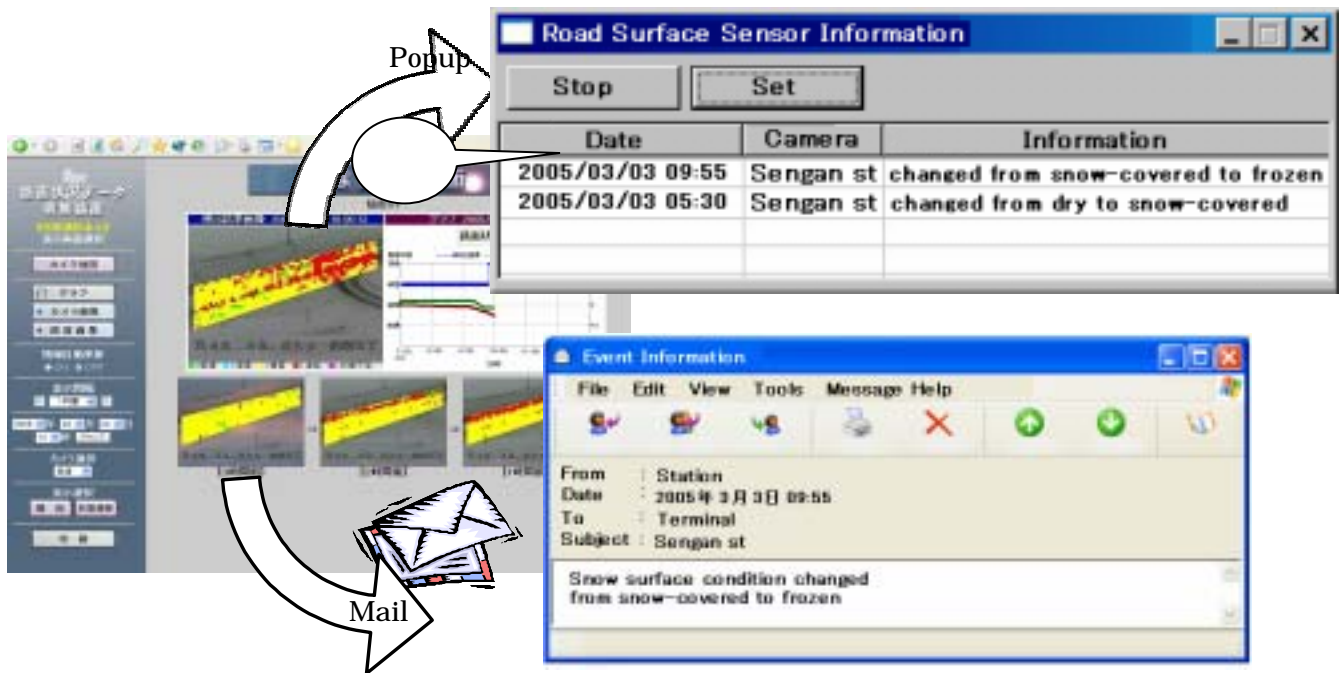


Fig. 4 Notification via Processing Terminal

To summarize the above, the visual image road surface sensors can be expected to have the following benefits.

Enable operators to select the appropriate timing for the application of freezing inhibitors.

Enable operators to select the appropriate amount of freezing inhibitors for the road surface conditions involved.

Enable operators to be aware of changes in phenomena without continuous monitoring the screens.

### Detection of Refreezing

To be able to detect refreezing, it is necessary to understand how a road surface freezes following the application of a freeze inhibitor. The onsite survey detailed in Table 1 was therefore conducted, enabling the actual refreezing of a road to be observed and the associated temperature of the road surface.

Table 1 Details of Onsite Survey

Period	5/1/20 15:00 ~ 5/1/2215:00、 5/2/21 14:30 ~ 5/2/23 10:30
Location	Road in front of Sengan Snow Clearing Station, Tazawako (Highway 46)
Method	Road surface examined visually and temperature measured every 10 minutes
Conditions	Dry, Wet, Accumulated snow, Ice

### Detection of Application of Freeze Inhibitors

To be able to detect refreezing, it is necessary to be able to detect whether a freeze inhibitor has been applied. The temperature of ice is known to drop rapidly when a freeze inhibitor is applied to it. Table 2 shows the times when the freeze inhibitor was applied, the amount applied, the times when the temperature of the road surface dropped and the amount by which these temperatures dropped during the period of the survey.

Table 2 Measurements of Drop in Temperature Following Application of Freeze Inhibitor

Time of application	Amount applied	Time when temperature dropped	Degree of drop in temperature
1/20 16:20	Unclear	-	-
1/20 21:48	40	21:59	3.2
1/21 02:41	20	-	-
1/21 15:42	15	-	-
1/21 20:36	20	-	-
1/22 06:18	20	-	-
2/21 16:08	20	-	-
2/22 06:24	15	06:50	1.0
2/22 07:32	35	-	-
2/22 16:06	20	-	-
2/22 21:44	20	21:50	1.2
2/23 06:05	20	-	-

The table shows that the temperature of the road surface sometimes dropped rapidly and sometimes did not. The temperature dropped rapidly when the road was already frozen, and did not drop when the road was unfrozen. This phenomenon occurs because the freeze inhibitor uses the energy of the ice to melt it. Fig. 5 shows the changes in the road surface temperature as the ice melts. The temperature slowly rises after dropping suddenly, due to nature's reducing difference between the temperature of the road surface and the atmospheric temperature to a minimum.

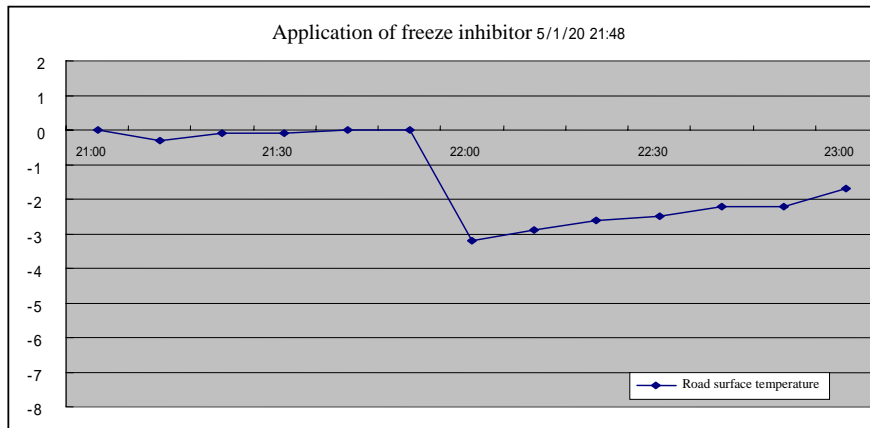


Fig. 5 Changes in Road Surface Temperature when Freeze Inhibitor Applied

We therefore established a rapid drop in the temperature of the road surface, followed by a gradual increase in temperature as the condition indicating that freeze inhibitor had been applied. We developed a program for sensor to detect this condition and tried this system. The results are shown in Table 3.

Table 3 Detection of Application of Freeze Inhibitor by Sensor

Time when applied	Time when detected
1/20 21:48	1/20 22:20
Not applied	1/22 7:10 (Misdetection)
2/22 06:24	2/22 06:50
2/22 21:44	2/22 22:10

The sensors accurately detected the fact that freeze inhibitor had been applied. The single case of misdetection is believed to have been caused by the occurrence of a change in the temperature of the road surface almost identical to that which occurs following the application of freeze inhibitor.

These results indicate the sensor with program has the ability to detect the application of freeze inhibitors after the surface of the road has frozen.

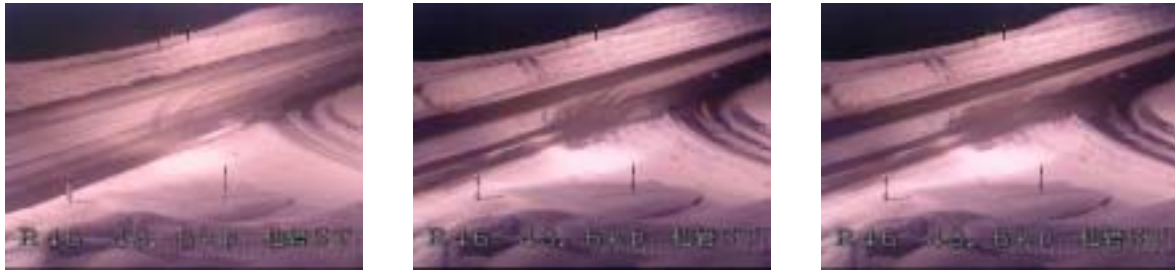
### Detection of Refreezing of Road Surface

While conducting the onsite survey, the surface of the road refroze twice following application of freeze inhibitor. Table 4 shows the time when the freeze inhibitor was applied, the temperature of the road surface before melting, the time when the ice melted, the time when refreezing occurred and the temperature of the surface of the road when refreezing occurred.

Table 4 Time when Refreezing Occurred

Time of application of freeze inhibitor	Road surface temperature before melting of ice	Time when ice melted	Time when refreezing occurred	Road surface temperature at refreezing
1/20 21:48	0	1/20 22:30	1/21 1:20	-0.9
2/22 21:44	-2.7	2/22 22:00	2/23 1:00	-5.5

Fig. 6 shows the road surface as it refreezes. It is clear that the area of moisture on the surface has increased following the application of the freeze inhibitor, but it is difficult to judge from the image that refreezing is occurring.



Before application 2/22 21:45    After application 2/22 22:55    After refreezing 2/23 1:00  
 Fig. 6 Changes in Road Surface Conditions from Application of Freeze Inhibitor to Refreezing

Fig. 7 shows the changes in the temperature of the road surface before refreezing occurs. The application of freeze inhibitor causes the temperature to drop rapidly, followed by a gradual increase until it eventually becomes stable. After a period of time the road surface then refreezes.

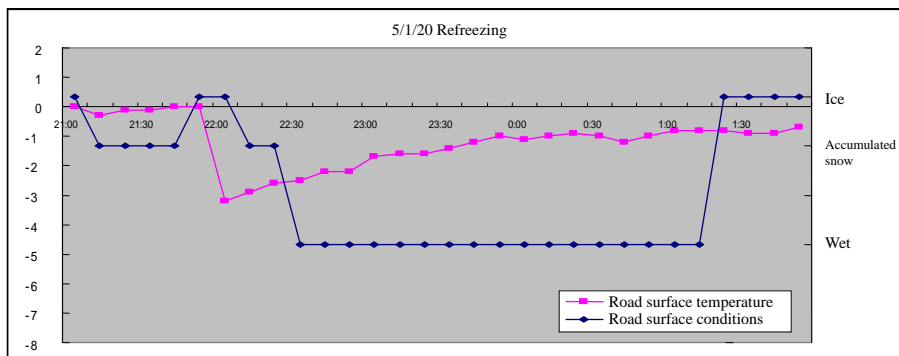


Fig. 7 Changes in Road Surface Temperature before Refreezing Occurs

The relationship between the temperature of the road surface and the concentration of freeze inhibitor can be explained as follows:

- 1) When freeze inhibitor is applied to a frozen road surface, it dissolves in the water at the periphery of the ice, forming an extremely high-concentration solution that melts the ice around it. Passing cars spread this solution over the road surface, and the ice melts across the entire road surface. During this process the temperature of the road surface drops rapidly.
- 2) As the ice melts, the concentration of the solution is diluted by water. In addition, the temperature of the road surface gradually increases by nature's reducing difference from the atmospheric temperature.
- 3) During the day, the snow melts and cars spread the solution over the road surface, causing it to become progressively more diluted. During the night, the temperature of the road surface, which had gradually risen, becomes constant or begins to decline, and the road refreezes. Because the water content of the solution freezes, its concentration becomes progressively higher. The solution therefore becomes progressively more resistant to freezing. It does not freeze completely but forms a sherbet-like mixture of ice and solution.

From the above, we can say that when the temperature of the road surface stops rising and either becomes constant or begins to decline, there is a potential for the road to refreeze. The visible image road surface sensor makes its final judgment on whether the road has frozen or not by means of a measurement of the road surface temperature and an internal threshold value for freezing. Therefore, changing the threshold value to the road surface temperature measured at the time when the temperature stopped increasing will enable the sensors to judge the transition from that of a wet road surface to a refrozen road surface after application of the freezing inhibitor. Specifically, knowledge of the transitions in the temperature of the road surface enable us to make the changes shown below, which respectively enable the sensor to judge the road surface as wet, when an application of freezing inhibitor is detected (when the temperature increases gradually after dropping rapidly), and as frozen when the freezing inhibitor becomes ineffective (when the temperature stops increasing).

- 1) Detection of application of freezing inhibitor (Rapid drop in road surface temperature followed by a gradual increase)

The temperature at which a road surface is judged frozen: The road surface temperature when the temperature rapidly drops

2) Detection of refreezing (When temperature stops increasing)

The temperature at which a road surface is judged frozen: The road surface temperature when the temperature stops increasing

These values were programmed into sensors and a simulation was conducted. The results are shown in Table 5 and Fig. 8. While slight deviations can be observed, the sensors were successful in detecting refreezing.

Table 5 Detection of Refreezing by Sensor

Observation result			Sensor result		
Time when freeze inhibitor applied	Time when ice melted	Time when refreezing occurred	Time when application of freeze inhibitor detected	Time when melting judged	Time when refreezing judged
1/20 21:48	1/20 22:30	1/21 1:20	1/20 22:00	1/20 22:00	1/21 1:10
2/22 21:44	2/22 22:00	2/23 1:00	2/22 21:50	2/22 21:50	2/22 23:00

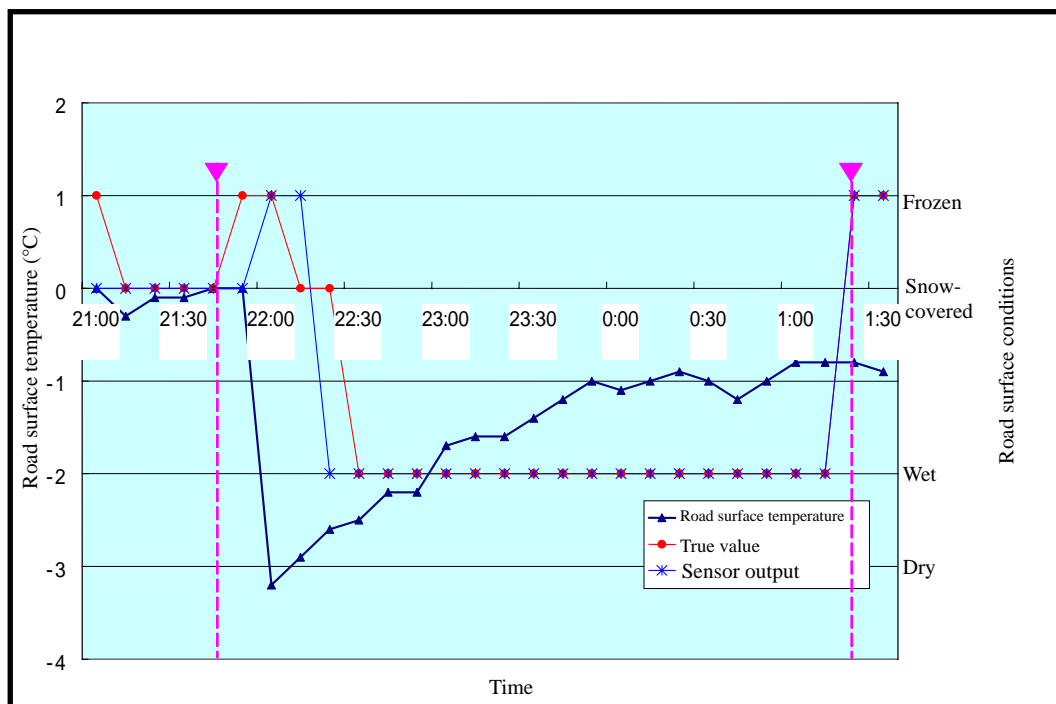


Fig. 8 Results for Detection of Refreezing on 1/20

## **Conclusion**

The use of visible image road surface sensors in road management enables a continuous monitoring of road surface conditions, and can additionally enable an early detection of signs of road freezing, and the application of a freeze inhibitor at an appropriate time. In addition, because the sensors can detect signs of refreezing, they will assist in judgments on whether or not to reapply freeze inhibitors, and can therefore be expected to significantly reduce the length of time during which roads are frozen. The efficient application of freeze inhibitors will also reduce both costs and impact on the environment.

Numerous types of road surface sensors have been developed in addition to visible image sensors. However, these sensors shows various problems, including low rates of successful detection and the ability to cover only a small area of the road surface, and their use in road management work has therefore been limited. Because visible image sensors can utilize existing CCTV infrastructure, they can be introduced at around the same cost as other sensors. The visible sensors are able to cover wide areas with an accuracy of over 80%, and therefore possess sufficient functionality and performance to enable their use in road management. The Akita river & Highway Road Management Office introduced visible image road surface sensors last year. We anticipate that broader introduction of the sensors in future applications will reduce the workload of road management personnel, increase the efficiency of road management and make our roads safer.