WINTER ROAD SURFACE MANAGEMENT TECHNOLOGY USING MAGNETIC SENSORS

Junichi OSHIMA [*1], Chuichi SHIMOMURA [*2]

Snow Research Center, Planning and Coordination Department
Telephone: +81-3-3261-2941/ Fax: +81-3-3261-2764
E-mail: *1 junichi@yukicenter.or.jp, *2 simomura@yukicenter.or.jp

1. Abstract

Information technology that has advanced with startling speed in the past few years is technology with the hidden potential for broad application to the field of winter road management, and expectations of its use have influenced research in many areas.
These circumstances have resulted in many research studies and development projects intended to provide both new hardware and software that can boost the efficiency of winter road surface management work. But on the other hand, it is now necessary to develop a new winter road surface maintenance system to meet the increasingly advanced public expectations of snow removal and to overcome chronic problems such as a shortage of workers and the aging of the available work force.

As one way to resolve these problems, we propose a winter road surface management system using magnetic sensors as a highly practical technology that will permit more stable and reliable performance of effective and efficient tasks including snow removal and icing prevention. Where this system is installed, magnetic sensors will detect the magnetic fields generated by an electric current passing through electric wires buried under road surfaces (below called “signal wires”) and the information obtained this way will be used to guide and support winter road management work. Specifically, it will be used for the following two purposes.

Use-i) Assisting road users (road management staff and workers plus ordinary users; drivers pedestrians, etc.) driving along the signal wires (below, “driving assistance”).
Use-ii) Providing road users with route location information by transmitting various kinds of data (multiple magnetic fields) in the signal wires (below, “route information assistance”).

Driving assistance technology for Use i) is an existing technology now used for truck guidance inside factory grounds. This technology can be used for high precision driving assistance for snow removal and anti-icing spreading personnel during accumulated snow and blowing snow conditions. And route information assistance technology for Use ii) can be used for route information assistance as a line: primarily for the provision of information about anti-icing chemical spreading sections and spreading quantities and snow blowing direction information for rotary snow removal vehicles. Studies have been carried out to develop methods of applying this system to winter road surface management that requires highly precise information by providing two kinds of assistance: driving assistance and route information assistance. We have carried out the following basic study of magnetic sensors in order to contribute to the development of a working system that can provide the above two uses.

Purpose of the Experiment: Can the magnetic sensors constantly detect information from the signal wires as winter road driving assistance technology? And can it be applied to multiple frequencies as a route information assistance technology?

Based on the above, we have confirmed that this technology is a system that can be used to manage winter road surfaces. This report introduces other cases of the application of this system. Figure 1 is an image of its application to assist an anti-icing chemical spreading vehicle.

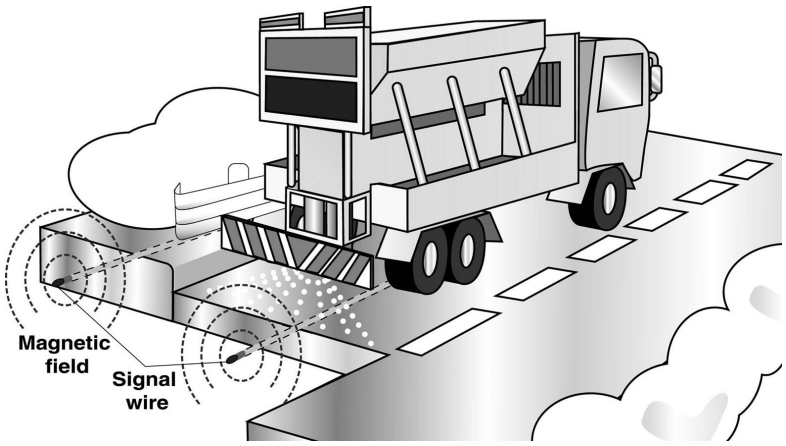

Figure 1. Use to Assist an Anti-icing Chemical Spreading Vehicle

2. Introduction

The recent progress in motorization has broadened the range of people's daily lives and industrial activities and has transformed the daily lives of people living in snowy parts of the country. And the development of information communication brought by the IT revolution of the past few years has created technologies with hidden potential in many areas of winter road management, and expectations of its use have influenced research in many areas.

In snowy cold regions, both the public and regional governments are demanding more of winter road surface management. The public's top priority is carefully planned efficient removal of snow from the roads, and road managers are eager to cut the quantity of anti-icing chemical spread on the roads to protect the environment and concrete structures from its effects. But despite the many needs that snow measures must satisfy, the high cost of dealing

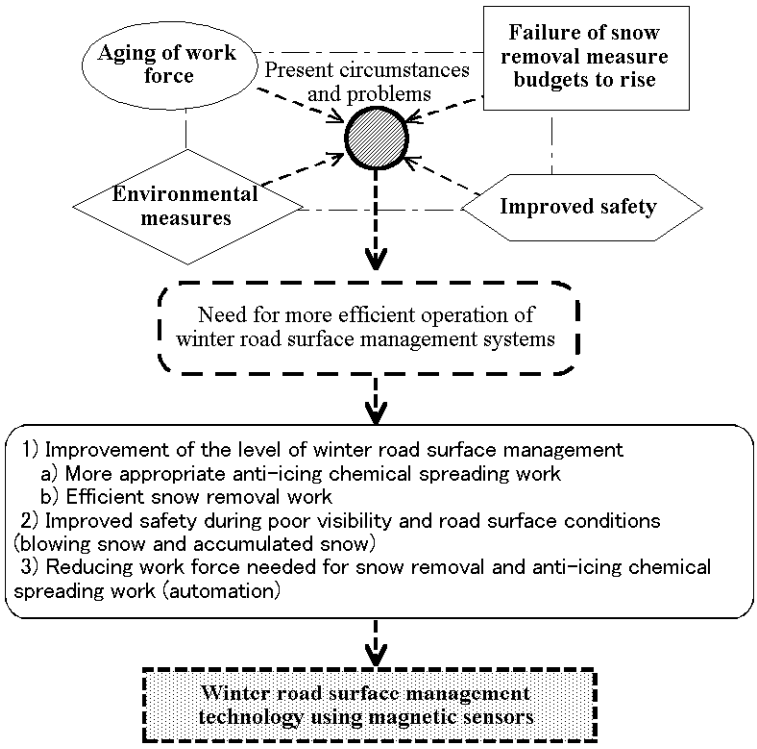

Figure 2-1-1 Background to the Research

with snow is a serious burden on the budgets of regional governments, making it difficult for them to meet everyone's expectations.

These circumstances have resulted in many research studies and development projects intended to provide both new hardware and software that can boost the efficiency of winter road surface management work. And it is now necessary to develop a new winter road surface maintenance system to overcome chronic problems that include a shortage of workers and the aging of the available work force (Fig. 2-1-1).

As one way to resolve these problems, we have carried out comprehensive studies encompassing cost efficiency, energy conservation, environmental conservation, etc. to research and develop methods of developing a guidance system using magnetic sensors as a highly practical system intended to permit more stable and reliable performance of effective and efficient tasks including snow removal and icing prevention, and we have carried out studies to establish it as a practical method for winter road management.

3. Outline of the guidance system

Guidance systems of many kinds have been developed thanks to the technological progress achieved in the information communication field in recent years. Table 3-1-1 shows an outline of the major guidance systems.

Table 3-1-1 Present State of Guidance Systems

Guidance method			System outline
Artificial satellites	GPS (independent positioning)		Using GPS data to provide accurate information about the locations of motor vehicles. Now used mainly to guide workers operating public works construction machinery.
	D-GPS		
	Others		
Light guidance	Infrared light		Detects bar codes (infrared radiation) and laser light (emitters installed on road sides) etc. primarily to guide motor vehicles etc.
	Laser light		
Magnetic guidance	Point positioning		Transmitters are installed in the centers of roads to guide motor vehicles etc.
	Continuous positioning	Surface	Magnetism transmission disks are continuously installed on road surfaces to provide guidance.
		Buried	**Wires etc. are embedded inside pavement to emit magnetic fields that guide vehicles.**

* Bold letters indicate this system.

The purpose of the guidance system is the total automation of vehicles, and generally, the three technologies shown in Table 3-1-2 are necessary to achieve this goal.

Table 3-1-2 Three Challenges Facing Automation

Challenges to be overcome to achieve automation of motor vehicles
1) Guiding the operators 2) Remote control 3) Safe machine operation (machine control)

Generally, the three challenges are faced and overcome in sequence, but the third that is machine control is now at the first stage of development. GPS guidance that can be used for the three kinds of guidance listed above will gradually become the principal guidance system in use as the number of cars equipped with terminals (car navigation systems) rises every year.

But regarding the use of a guidance system for winter road management, we have defined the characteristics of the above guidance system as shown in Table 3-1-3 and have concluded that a guidance system using magnetic sensors is appropriate for use in winter road management.

Table 3-1-3 Special Features of Guidance Systems

Guidance technique	Characteristics of each guidance system
Artificial satellite	Its position information is now approximate and it is difficult to use it in mountains when snow is blowing or has accumulated on the ground.
Light guidance	It is difficult to use during blowing snow conditions or when snow has accumulated on the ground. It is also costly.
Magnetic guidance	It can be used in mountainous regions when snow is blowing or has accumulated on the ground, and the embedded type provide particularly superior detection precision and maintainability.

On the assumption that the use of combined systems integrating three guidance systems GPS, light, and magnetic type will increase along with infrastructure provision, this research project also studied GPS functions as a potential future supplementary function.

4. Outline of the guidance system using magnetic sensors

4-1. Outline of the guidance system

As shown in Fig. 4-1-1, it is an integrated guidance system for motor vehicles etc. that provides two kinds of assistance by passing an AC electric current through electric wires buried under road surfaces (below called “signal wires”) (Table 4-1-1).

Specifically, road users can benefit from the two kinds of assistance shown in Table 4-1-1.

Table 4-1-1 Two Assistance Technologies

1) Assisting road users driving along the signal wires (below, “driving assistance”).
2) Providing road users with linear information about the route by transmitting various kinds of data in the signal wires (below, “route information assistance”).

Driving assistance technology 1) is an existing technology used for applications such as truck guidance inside factory grounds. This technology can be used for high precision driving assistance for snow removal and anti-icing spreading vehicle personnel during accumulated snow and blowing snow conditions. And route information assistance technology 2) can be used for route information assistance as a line: primarily for the provision of information

about anti-icing chemical spreading sections and spreading quantities and snow blowing direction information for rotary snow removal vehicles. Studies have been carried out to develop methods of applying this technology to winter road surface management that requires highly precise information by providing two kinds of assistance: driving assistance and route information assistance.

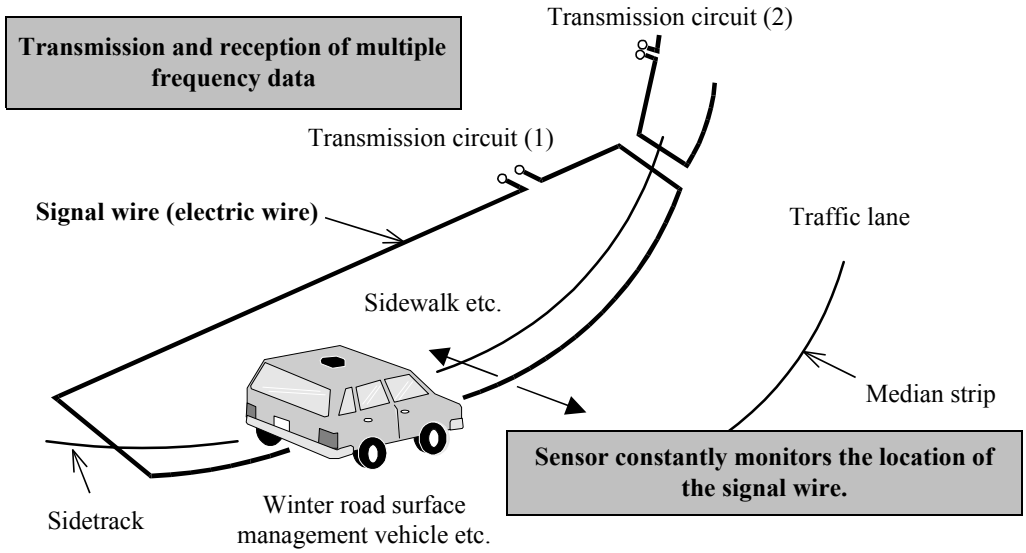

Figure 4-1-1 Outline of the Guidance System

4-2 Principles of the system

As shown in Figure 4-2-1, this system consists of a transmission sub-system and reception sub-system. Below, the system principles are explained separately for the transmission and the reception sub-systems.

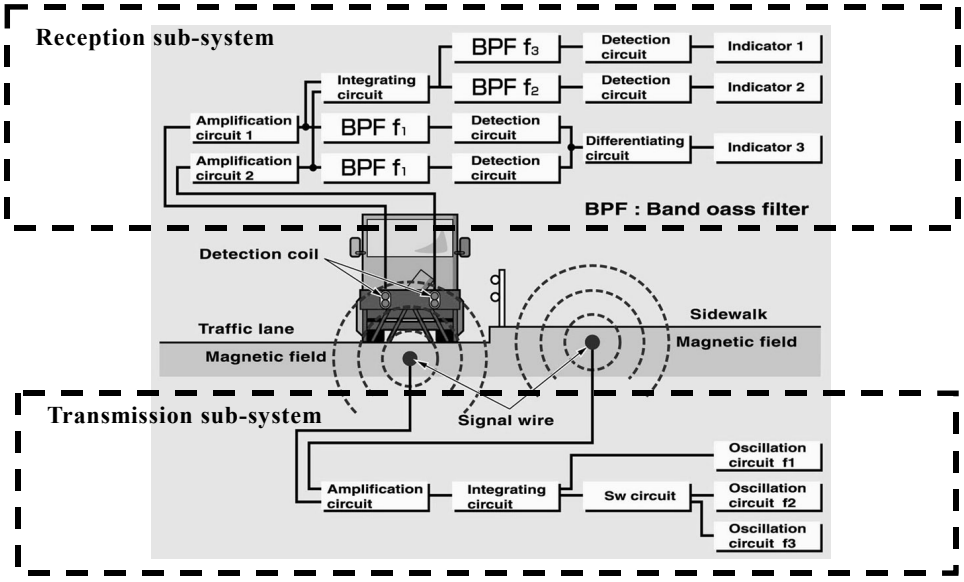

Figure 4-2-1 System Principle Diagram

1) Transmission sub-system

The transmission sub-system is equipped with transmission circuits that output frequency signals f_1 and f_2, (f_3…) to the signal line that is installed in a loop under the surface of the traffic lane and the sidewalk (etc.). This output is received and its frequency is integrated, amplified, then connected to the signal line to produce an AC magnetic field.

Figure 4-2-2 shows examples of transmission circuit layouts. The use of driving assistance (f_1) and road information assistance (f_2), (f_3…) are considered primarily as types B, C, and D in this system.

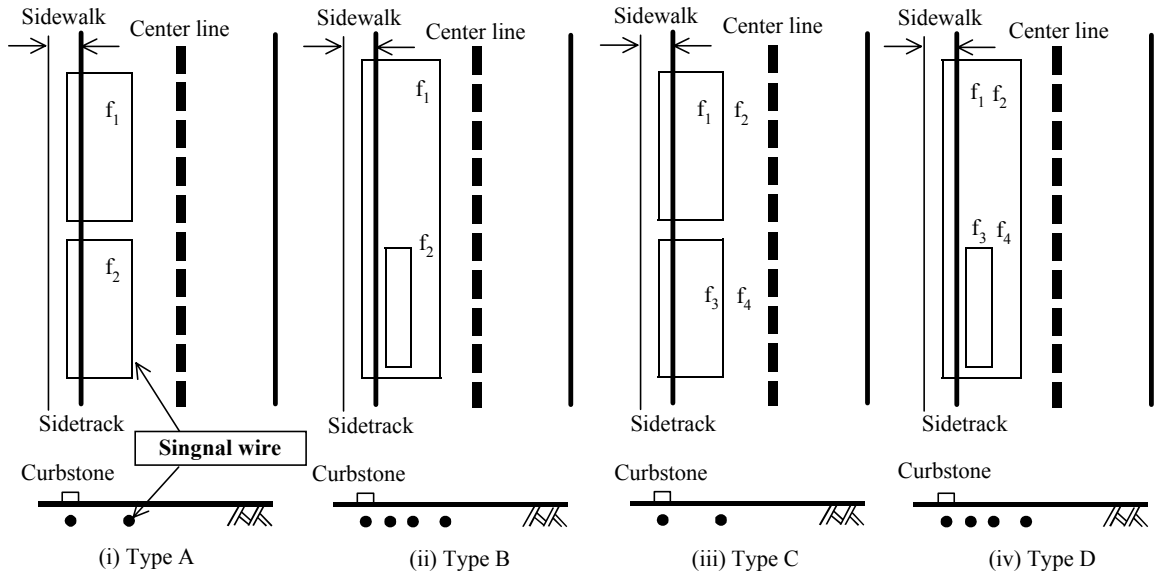

Figure 4-2-2 Transmission Sub-system Circuit Patterns

2) Reception sub-system

The reception sub-system is a driving assistance sub-system that consists of detection coils installed in vehicles (below, "sensor"), first band pass filter that receives sensor output and detects f_1 (below, "BPF_1"), BPF_2 that receives sensor output and detects f_2, and indicators. When it detects f_1 from the above AC magnetic field, it gives process indication $_1$ (for example, in the case of rotary snow removal vehicle guidance, blow the snow in a certain direction), and if it detects f_2, it gives process indication$_2$ (for example, stop blowing snow).

5. Basic testing of the magnetic sensors

5-1. Outline of the basic testing

To clarify the characteristics of the magnetic sensors, basic testing was done on a prefectural road and in a parking lot in Nakago-mura in Nakakubiki-gun in Niigata Prefecture.

Purpose of the testing: When used as part of a guidance system, will the magnetic sensors detect the signal wires under all conditions (driving time, when under accumulated snow or buried in soil, effects of noise, etc.)?

As shown in Figure 5-1-1 and in Photograph 5-1-1, the testing was done by attaching two sensors, sensor A and sensor B, on the left and right sides of the front bumper of a motor vehicle to perform both driving and static tests of both sensors. This report describes the results of the following tests done in March 2001, but only presents the conclusions of other tests.

Photograph 5-1-1 Magnetic sensor

Test 1) Basic test of the magnetic sensor under accumulated snow Test 2) Detection test of a non-uniform magnetic field Test 3) Effects of a national highway etc.

There are two kinds of sensor detection method, so basic tests of each were performed.

1) Center detection	When two sensors are on opposite sides of the signal wire (Photograph 5-1-2)
2) Side-wire detection	When a signal wire is located outside of the two sensors (Photograph 5-1-3)

The test results confirmed the strength of the magnetic field emitted by the signal wire (output by voltage) applying the principle of electromagnetic guidance (if the sensor nears the magnetic field area, electromotive force (e) is generated in the sensor).

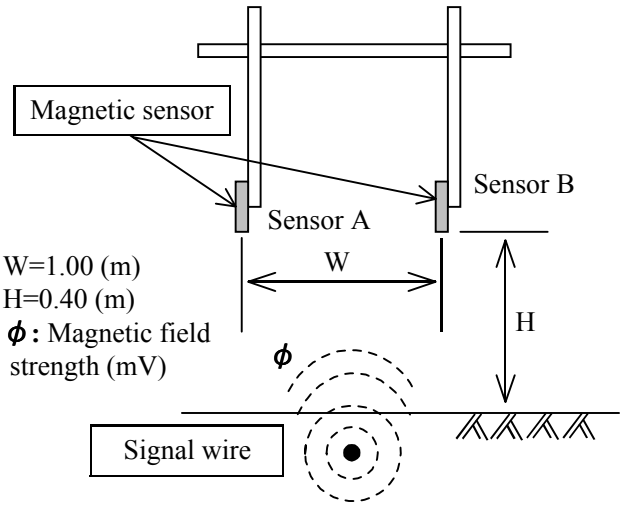

Figure 5-1-1 Magnetic Sensor Installation Locations

Photograph 5-1-2 Center Detection

Photograph 5-1-3 Side-Wire Detection

5-1-1. Basic test of the magnetic sensor under accumulated snow

Figure 5-1-2 shows the test method used to simulate accumulated snow on a winter road surface. This test was done simulating the accumulation of snow above a signal wire by in-

stalling the signal wire in the side ditch of a parking lot then filling the ditch with snow. Because this system is expected to provide high precision guidance even under the worst possible winter road surface conditions, it must collect accurate information from a signal wire even when the road surface is covered with snow.

Photograph 5-1-4 shows the way the signal wire was buried. The sensor's output values (mV) were compared for the section with and section without accumulated snow to study the effects of the snow.

Photograph 5-1-4
Signal Wire Covered with Snow

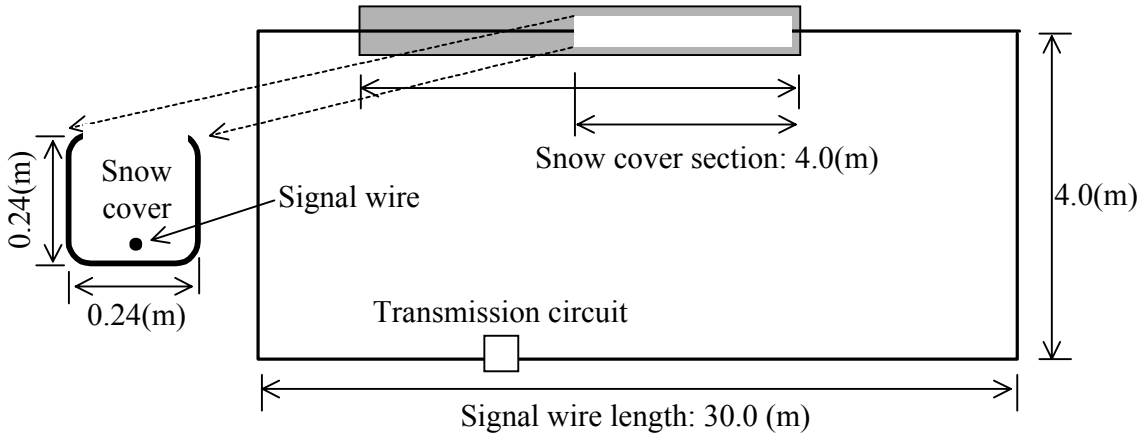

Figure 5-1-2 Accumulated Snow Test Field (Parking Lot)

The results of the testing are shown in Figs. 5-1-3 and 5-1-4. The precision of center detection was verified by the fact that the output values are symmetrical above the signal wire, which shows that the sensors continuously detected the location of the signal wire. And "above the signal wire" (approx. 1.61 mV) shown here indicates that the center of the space between the two sensors is above the signal wire. And in the side-wire detection case, because sensor A was closer to the signal wire than it was during center detection, output values obtained were higher than those obtained by center detection.

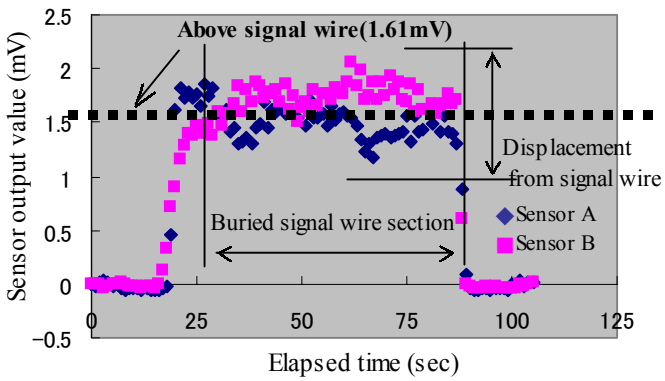

Figure 5-1-3 Accumulated Snow Test Results (Center Detection)

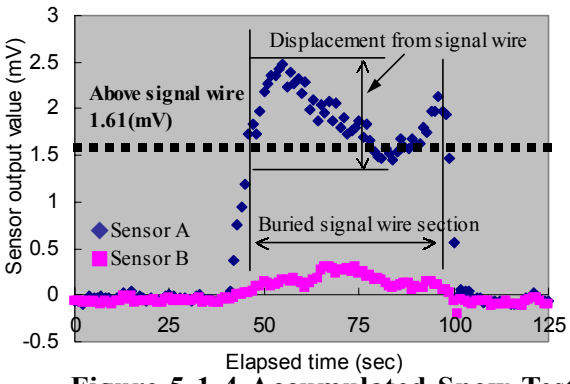

Figure 5-1-4 Accumulated Snow Test Results (Side-Wire Detection)

5-1-2 Non-uniform Magnetic Field Detection Test

The transmission sub-system of this system must transmit different signals (magnetic field) inside a uniform magnetic field. in order to provide route information. But a signal wire installed so that the current flows forward produces a uniform circular magnetic field in the direction the current flows. There are various ways of generating a magnetic field that differs from this uniform magnetic field, but we have proposed installing the signal wire as shown in Photograph 5-1-5 as a safe and reliable method. The results reveal that it is possible to receive output of magnetic fields that clearly differ as shown in Fig. 5-1-5 by side wire detection. We have also confirmed that output is increased within a certain range by enlarging the circular shape (diameter) of the signal wire

Photograph 5-1-5 Non-uniform Magnetic Field

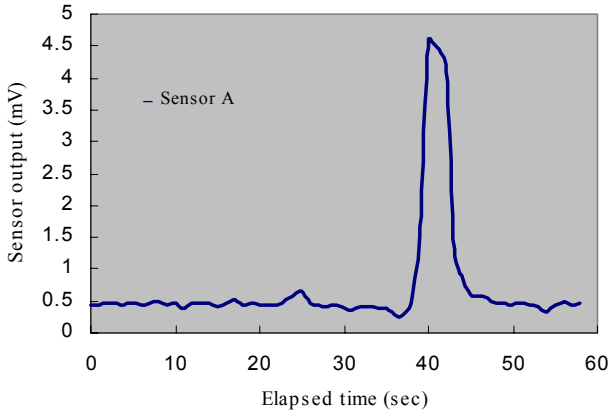

Figure 5-1-5 Test Results (Side-Wire Detection)

5-1-3 Effects of a National Highway Etc.

In recent years, electromagnetic waves (electric waves) of various kinds have been generated on National Highways, in our homes, and other places where people spend their daily lives. All devices that use electricity emit electric waves, even those that do not use electric waves, so it is necessary to find out if they effect this system. We drove a test vehicle on a National Highway and through a residential district and compared its effects with the output values in Fig. 5-1-3. The effects are extremely small as shown by the results in Fig. 5-1-6.

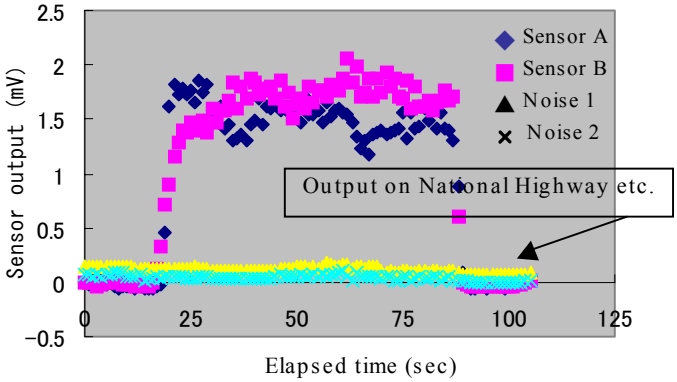

Figure 5-1-6 Effects of a National Highway Etc.

6. Test results and considerations

This testing was performed to clarify the basic characteristics of the magnetic sensors in preparation for their use in a completed working guidance system: specifically, determining if the magnetic sensors detect the signal wire under all conditions (driving time, when it is under accumulated snow or buried in soil, effects of noise, etc.).

As the photographs in section 5-1 have shown, the sensors used were simple, but were adequate to verify the objectives of this test.

Table 6-1-1 shows the conclusions obtained from the testing.

Table 6-1-1 Test Items and Conclusions

Test items	Test Outline	Conclusions
1) Basic test of the magnetic sensors	Does it detect the signal wire under all conditions (driving time, when it is under accumulated snow or buried in soil)?	The stipulated detection was performed during both center and side-wire detection.
2) Non-uniform magnetic field detection test	Can it detect multiple magnetic fields?	It could detect different magnetic fields in a uniform magnetic field.
3) Effects of National Highways etc.	Study the effects of driving on a National Highway in a vehicle equipped with the magnetic sensors	Effects of magnetism on a National Highway are extremely small

7. Methods of using the system and future directions

7-1. Example of its application to anti-icing chemical spreading

Figure 7-1-1 presents an image of the application of a guidance system using magnetic sensors to guide anti-icing chemical spreading vehicles. When spreading anti-icing chemicals it is important to plan the work by first clarifying a) when to spread it, b) where to spread it, and c) how much to spread on the spreading route.

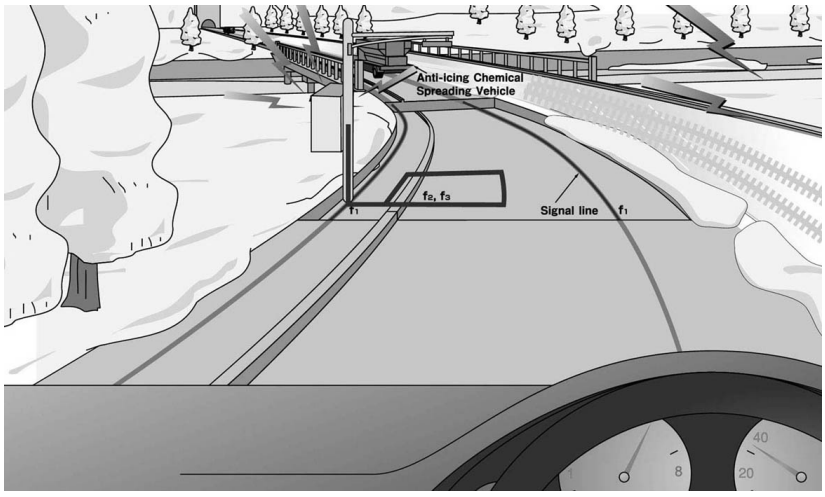

Figure 7-1-1 Image of the Application of the System to Guide Anti-icing Chemical Spreading Vehicles

This system can provide spreading assistance to help a road manager decide where to spread the anti-icing chemical and how much of it to spread by providing linear route information—"set spreading quantity" and "location information" as shown on the lower left corner of the screen in Fig. 7-1-1 for example—at the same time as it can provide driving support information to guide the vehicle by helping the operator confirm safe operating locations, even when the visibility is poor and the road is covered with snow. Therefore, the introduction of this system to anti-icing chemical spreading work is counted on to make the work more efficient and safer for the operators at the same time as it is expected to reduce the quantity of chemical spread and lower costs.

7-2. System Application Example

1) Rotary snow removal vehicle

Rotary snow removal vehicles require precise driving assistance, because they are often dispatched when conditions are bad—when the visibility is poor or the road covered with accumulated snow for example—and they are driven slowly. This system can provide constant and highly precise driving guidance at specified locations, even on small radius curves, in blowing snow, and when there is a thick layer of snow on the road. It can provide route information assistance by giving the operator advance route direction information needed to switch the direction the snow is blown, the locations of manholes, etc.

2) Sidewalk snow removal and guidance for pedestrians (Fig. 7-2-1, Fig. 7-2-2)

To meet the needs of today's aging society by forming living space that anyone can use safety without anxiety in order to participate fully in social life, this system can be used for efficient and safe sidewalk snow removal and pedestrian guidance as shown in the figure in order to help provide walking space that everyone can use safely and comfortably, even in the winter.

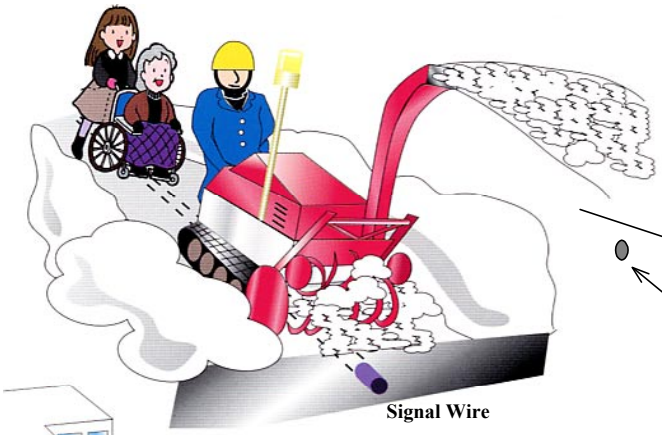

Figure 7-2-1 Application to Sidewalk Snow Removal

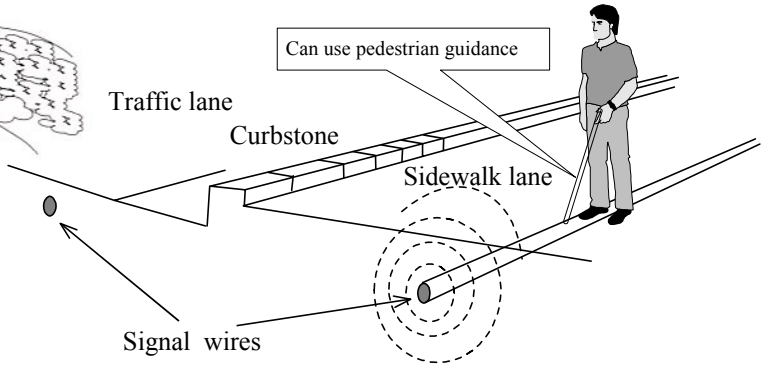

Figure 7-2-2 Application for Pedestrian Guidance

3) Line of sight guidance during blowing snow conditions and other forms of assistance

Delineators etc. are used to guide vehicles, pedestrians, etc. under blowing snow conditions when visibility is poor, but this system can provide highly precise driving assistance when snow is falling and accumulating by providing route assistance as a line. At the same time as it can be used to transmit and receive information, burying it under the center line and roadside will make it an effective white line maintenance method.

8. Summary and future challenges

This study confirmed that a guidance system using magnetic sensors is highly practical as a winter road surface management tool. But the following technologies must be developed and verified before this system can actually be deployed.

Table 8-1-1 Future Challenges

Challenge	Content
1. Vehicle control	Vehicle control to provide machinery operating assistance in management vehicles.
2. Meteorological forecasting system introduction	Assistance with the task of deciding when to dispatch snow removal and anti-icing chemical spreading vehicles by introducing air temperature and snowfall prediction system
3. Transmitting circuit control	Remote control from public works offices of signals in transmission circuits in order to handle information about rapidly fluctuating winter road surface conditions in real time.

Sources

1) J. Oshima: Application of a Magnetic Vehicle Guidance System to Winter Road Surface Management, July 2000, *Yuki* (Snow), No. 40, pp. 62-66