Proposal and Evaluation of a Walking Support System for Visually Impaired People (Application Possibility of Phosphors)

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Abstract

Visually impaired people can possibly feel stress and anxiety while walking at pedestrian crossing and vehicle doorway at train stations. We propose a walking assistance system in order to (1) provide accurate information (existence and the type of braille blocks) via a cane and (2) inform them the place's information via the cane while they are at the places where they can possibly feel stress and anxiety. In contrast to the previous works of using electronic devices (RFID (Radio Frequency Identifier) tags), we take an approach of using chemical substance (phosphors) as guiding object. In our elementary experiments, we made samples with 5% of phosphor powder by using resin material and could observe the existence of it. This result indicates the potential feasibility of our system.

Keywords: visually impaired people, walking support, smart cane, phosphors.

1. Introduction

Braille blocks help the visually impaired people walk autonomously. Braille blocks were internationally standardized based on the Japanese Industrial Standards and are currently used in more than 150 countries⁽¹⁾. As shown in Fig. 1, braille blocks comprise leading and warning blocks (length = width = 30 cm), which have different surface projections. A block with bar-shaped projections indicates the direction to walk, and a block with dot-shaped projections indicates the existence of a potentially dangerous location place, e.g., a pedestrian crossing, or a service that guides the visually impaired people, e.g., a signboard written in braille, near the blocks. The visually

impaired people understand the meaning of each block by sensing the shapes through the soles of their feet and/or a white cane.

Although braille blocks can guide the visually impaired people, they are not always present in places, such as pedestrian crossings (Fig. 2), where they may be helpful because they may cause other pedestrians, motorcycles, and vehicles to slip when the road surface is wet or icy. In addition, toddlers and elderly people are to stumble over them, which could cause a traffic accident. However, if visually impaired people who use a cane cannot distinguish between a pedestrian crossing and a roadway, they tend to feel high stress and anxiety, particularly if they have to cross a street in a limited amount of time.

Entering and exiting the doors of a train can also be a stressful experience (Figs. 3 and 4) because the distance between the warning blocks and the edge of the platform is not standardized throughout the world and there is a gap between the doorway and the platform. In addition, it is difficult for the visually impaired people to distinguish whether their cane is touching the doorway or the floor of the vehicle. This is particularly stressful because similar to a pedestrian crossing, people are expected to board and exit as quickly as possible.

Many visually impaired people use canes to detect objects that support or hinder walking. We believe that stress and anxiety of the visually impaired people would be reduced if they could distinguish the places touched by the cane. Thus, we propose a walking assistance system to provide accurate information, i.e., the presence and type of braille blocks, and inform the visually impaired people regarding the places where they can possibly experience stress via the cane. We conduct basic experiments to verify the feasibility of the proposed system.

The remainder of this study is organized as follows. In Section 1.1, we introduce other walking assistance systems for the visually impaired people and clarify the differences between the previously proposed systems and our system. In Section 2, we describe our proposed smart cane system. In Section 3, we report the results of preliminary experiments that were conducted to verify the feasibility of the proposed system. We discuss the feasibility of our system in Section 4 and present conclusions in Section 5.

Fig. 1. Leading block (left) and warning block (right).

Fig. 2. Pedestrian crossing and braille blocks.

Fig. 3. Vehicle doorway and braille blocks.

Fig. 4. Gap between the platform and the vehicle.

1.1 Related work

A system that recognizes the existence and type of braille blocks, obtains user location information via a smart cane, and employs wearable devices to support walking where there are no braille blocks has been previously proposed⁽²⁾. In this system, the location data of each braille block and its type are stored in a passive RFID tag (range, 15 cm) embedded in the braille block. An RFID reader is embedded on the tip of the cane. The user can recognize the existence and type of braille block, and the system can obtain the user's current location information via the cane. If there are no braille blocks, e.g., at a pedestrian crossing, the system calculates the user's movement locus using the location information obtained from warning blocks that are positioned in front of the pedestrian crossing and the data detected by two sensors, i.e., accelerator and geomagnetic sensors, in the wearable devices. Based on the calculation, the system helps users to stay within the pedestrian crossing boundaries.

However, the geomagnetic sensor might be affected by electromagnetic waves caused by vehicles stopped at the pedestrian crossing; thus, the movement locus might not be accurately calculated⁽²⁾. If this system was implemented at the doorway of a public transport vehicle, the same problem might occur. Moreover, due to safety concerns, braille blocks are not usually positioned at vehicle doorways. Consequently, users cannot distinguish between the doorway and the vehicle's floor and are likely to experience anxiety while entering or exiting the vehicle. In addition, as this system uses mechanical guidance objects, i.e., RFID tags, mechanical malfunctions could occur.

Table 1. Comparison of previously proposed systems.

	Related study ⁽²⁾	Related study ⁽³⁾
Impact of electromagnetic waves (walking support without braille blocks, e.g., pedestrian crossing)	Affected	Not affected
Distinguishes vehicle doorway and the vehicle floor	No	Yes
Labor for burying guiding objects	Required	Required
Risk of mechanical malfunction of guiding objects	Yes	Yes

Another system⁽³⁾, which differs from the abovementioned system⁽²⁾, proposes positioning passive RFID tags with an adjacent magnetic field-type antenna in a grid shape at regular intervals under the platform. Location information is stored in each RFID tag. This system can recognize the location via an RFID reader embedded on the tip of the cane to determine whether it is a dangerous place, e.g., the edge of the platform.

Although burying RFID tags under pedestrian crossings, vehicle doorways, and vehicle floors in a grid shape at regular intervals is ideal, it is impractical. Burying RFID tags requires calculating the optimal number of RFID tags and their burying position⁽³⁾, and additional labor is required to bury the tags at accurate positions. Note that additional labor is also required to embed RFID tags into braille blocks. Moreover, similar to⁽²⁾, this system could experience mechanical malfunctions as it also uses mechanical guidance objects.

A comparison of two previously proposed systems^(2,3) is shown in Table 1.

1.2 Requirement specifications

Based on the considerations described in Section 1.1, the proposed walking assistance system should fulfil the following requirements:

- (1) The system is less prone to electromagnetic waves in locations without braille blocks.
- (2) The system can recognize the location of guiding blocks, warning blocks, pedestrian crossings, vehicle doorways, and vehicle floors using the cane.
- (3) The system does not require to calculate the position of guiding objects before burying them and does not significantly affect current construction methods.
- (4) The risk of the malfunctioning of the guiding objects is low.
- (5) Unlike passive RFID tags, the guiding objects do not require batteries.
- (6) Similar to RFID tags, the guiding objects can be mass produced.

1.3 Prerequisites

We focus on locations where the visually impaired people can possibly experience stress and anxiety, e.g., pedestrian crossings and vehicle doorways. We also assume that canes can be equipped with batteries. Using smart canes with batteries has been previously proposed^(2,3), and such canes are commercially available⁽⁴⁾.

2. Proposed system

2.1 Concept

To satisfy these requirements (see Section 1.2), we use chemical substances rather than mechanical devices, i.e., RFID tags, as the guiding objects. In particular, we use phosphors. Previously, phosphors have been used for authenticity verification of artifacts⁽⁵⁾, bio-imaging⁽⁶⁾, and product tracing⁽⁷⁾. Phosphors are luminescent, i.e., they emit light when exposed to radiation, such as ultraviolet light. This phenomenon is known as optical excitation. If we adjust the chemical composition of phosphors, we can observe five types of emission from only a single light source. We allocate different phosphors to guiding blocks, warning blocks, pedestrian crossings, vehicle doorways, and vehicle floors. We mix each phosphor with the materials such as synthetic resin, cement, and asphalt, and harden the mixture under appropriate conditions. Thus, as shown in Fig. 5, the system can distinguish different locations using a cane that has the light source and light-receiving units embedded on its tip.

A glass phosphor is shown in Fig. 6. This phosphor is a transparent, stable oxide that can withstand exposure to acids and alkalis and respond to optical excitation at temperatures greater than 1,000 °C. In addition, it has a low risk of affecting the human body or the environment, and its durability and ability to respond to optical excitation is semi-permanent⁽⁵⁾. Thus, it is an appropriate phosphor for the proposed system.

Fig. 5. Concept of the proposed system.

Fig. 6. Glass phosphor.

Fig. 7. System configuration.

2.2 System configuration of smart cane

The system configuration is shown in Fig. 7. The smart cane comprises a light source unit, light-receiving unit, data processing unit, data transmission unit, and power unit. The function of each unit is explained as follows:

(a) Light source unit: This unit optically excites the phosphors contained in the guiding objects (e.g., braille blocks) and includes a modulator that modulates the light generated from the light source. The light is modulated in order to allow the data processing unit to identify whether the received light is derived from the light source unit, thereby allowing the system to avoid errors when it receives disturbance light of the same wavelength.

(b) Light-receiving unit: This unit comprises a photo diode that receives light and a demodulator that demodulate the received light.

(c) Data processing unit: This unit comprises a processor that analyzes the demodulated light and determines locations using the cane according to five unique wavelengths and their corresponding location information.

(d) Data transmission unit: This unit can inform users about the contact made by the the cane in several ways, e.g. using a bone conduction speaker and a vibration function.

(e) Power unit: This unit supplies electric power to activate and operate the other units.

2.3 Embedding a guiding object

Two systems^(2,3) have proposed embedding passive RFID tags in braille blocks. To use current construction methods, we propose a straightforward way to add and mix phosphor powder with materials required for developing guiding and warning blocks, pedestrian crossings, vehicle doorways, and vehicle floors. In the following sections, we introduce ways to add phosphor powder while mixing other materials.

2.3.1 Guiding and warning blocks

Guiding blocks comprise cement, ceramic, and

synthetic rubber/resin, and each manufacturing procedure has a forming process after mixing the materials. Thus, phosphor powder can be contained in braille blocks by mixing it with materials at an appropriate ratio.

2.3.2 Guiding and warning blocks

Generally, pedestrian crossings are painted on the surface of a paved asphalt or cement road using white paint. This paint is heated to approximately 200 °C before painting because it forms a powder at normal temperatures. Thus, phosphor powder can be included in the pedestrian-crossing paint at an appropriate ratio when creating a mixture of asphalt or cement and aggregate and when melting the white paint.

There are two ways to form a pedestrian crossing. One is to paint white paint after freshly paving a road. The other is to paint white paint on the surface of an existing road. For the former case, phosphor powder can be added using the following method.

Asphalt pavement is formed by spreading a mixture of asphalt and aggregate on the surface of the basement after heating it to approximately 130 °C–190 °C. Conversely, cement pavement is formed by spreading a mixture of cement, water, and aggregate on the surface of the basement. Thus, we propose a method to add phosphor powder at an appropriate ratio when preparing the asphalt or cement mixture.

For the latter case, phosphor powder can be added using the following method.

In general, to reinforce the surface of the asphalt or cement pavement, a method to splay a methacrylic resin liquid and harden it at normal temperature is used. Thus, we propose a method to splay the liquid with an appropriate amount of phosphor powder onto the surface of the pavement based on the above method. White paint is applied after hardening the splayed methacrylic resin.

With these methods, users can recognize the presence of a pedestrian crossing and walk on it using their cane as phosphor can be included in an entire pedestrian crossing. In addition, in contrast to the colored paving, the appearance of the crosswalk does not drastically change after applying the abovementioned methods; thus, other pedestrians and drivers do not experience a sense of discomfort while passing over the pedestrian crossing.

2.3.3 Vehicle doorway

Generally, vehicle doorways are constructed by laying asphalt or cement blocks on the basement. Thus, phosphor can be included in entrances constructed using the methods described in the previous section.

2.3.4 Vehicle floor

Generally, vehicle floors must have non-flammable properties; thus, a flame retardant is added to the primary material (a synthetic resin, e.g., polyvinyl chloride, polyethylene, and polypropylene⁽⁸⁾). Thus, the phosphor can be included in the entire vehicle floor by mixing a synthetic resin, a flame retardant, and an appropriate amount of phosphor powders before forming floors.

3. Experiments

We conducted preliminary experiments to verify the feasibility of the proposed method. In these experiments, we observed the change in the intensity of the emitted light caused by optical excitation based on the change in the intensity of the light source and the amount of phosphor powder included in the samples.

We focused on three types of phosphors provided by Phosphor Technology, Inc. as sample phosphors for these experiments. These phosphors emit different visible light bands with different peak wavelengths when they receive near-infrared light with a 980-nm peak (blue: peak wavelength of 480 nm, green: peak wavelength of 554 nm, and red: peak wavelength of 661 nm). The five locations described in Section 2.3 can be defined using three types of phosphors with or without mixing in six combinations with one or two peak wavelengths. The safety of these phosphors has been proven, and they have a high melting point (approximately 1,100 °C); therefore, they are applicable to each method described in Section 2.3. In our experiments, we used one phosphor with a peak wavelength of 554 nm.

3.1 Experiment 1 (Sample making)

We prepared samples comprising epoxy resin and phosphor powder (Fig. 8). We used epoxy resin because it is easy to prepare samples with paint and powder, it has considerable amount of hardness, and its risk of affecting the human body and environment is low. We determined the weight percentage of phosphor powder (5%, 10%, 20%, and 40%) to epoxy resin, and prepared four samples with a diameter of approximately 4 cm and thickness of approximately 4 mm. We confirmed that each sample hardened well; however, with greater amounts of phosphor powder, the glaze of the epoxy resin was reduced.

3.2 Experiment 2 (Relation between the amount of phosphor and emission intensity)

We used the experimental device shown in Fig. 9 and

Fig. 8. Epoxy with phosphor samples.

Fig. 9. Experimental device.

Fig. 10. Weight percentage of phosphor and optical spectrum (top: 40%; bottom: 5%).

observed how the emission intensity changes by optical excitation when we changed the amount of phosphor

powder in each sample with a fixed distance between the light source and the sample. We set the distance from the light source to the base of the experimental device to 5 cm, the wavelength of the light source to 980 nm, the input current for the light source to 150 mA, and the distance from the light source to the receiving light guide to approximately 1 cm.

Figure 10 shows the optical spectrum of the samples (40% and 5% weight percentage). A peak wavelength of 980 nm from the light source and 554 nm (green) from the phosphor were observed. Although we employ only a single light-receiving guide, we observed the emission intensity from even the 5% sample, and as more phosphor power was added, the emission intensity increased.

4. Considerations

In this section, we consider the feasibility of the proposed system

4.1 Incorporating guiding objects

A previous study⁽²⁾ proposed embedding RFID tags in braille blocks, and another study⁽³⁾ proposed burying RFID tags in a reticular pattern at a regular interval in a platform. The RFID tag antenna is easily bendable; thus, in the former study, a method to embed RFID tags in braille blocks without bending is required. In addition, for the latter study, a method to bury RFID tags in a reticular pattern at a regular interval and pour the cement or asphalt mixture or place cement blocks is required. These methods must be considered along with current constructing methods, and these measures are also required for constructing pedestrian crossings and vehicle doorways.

Moreover, the proposed system can embed guiding objects (i.e., phosphor powder) more easily than previous studies^(2,3) because phosphor powder can be simply added to the construction materials with no major modifications to current construction methods.

4.2 Requirements

In this section, we describe whether our system satisfies the six requirements described in Section 1.2.

Requirement 1: The proposed system does not use any geomagnetic sensors to support user walking where there are no braille blocks; thus, the system is not affected by electromagnetic waves caused by vehicles. Therefore, our system appears to satisfy Requirement 1.

Requirement 2: The proposed system is designed to

distinguish each location by observing the received emitted light caused by optical excitation because phosphors with different wavelength peaks are included in each location. In addition, it is designed to use a modulator (in the light source unit) and demodulator (in the light-receiving unit) to avoid disturbance light when distinguishing the given location. Thus, the proposed system appears to satisfy Requirement 2. However, our system requires improvement for accumulating sufficient emitted light because the emission intensity by optical excitation is weaker than that of the light source. For example, constructing the tip of the light-receiving unit similar to a parabola antenna and increasing the number of light-receiving units could be considered to increase the amount of receiving light.

Requirement 3: Our system does not require accurate calculation of the positions of the guiding objects or modifications to current construction methods for including the guiding objects (phosphor powder) in five locations because we use a simple procedure to add an appropriate amount of phosphor powder to other materials. Thus, the proposed system appears to satisfy Requirement 3.

Requirement 4: Phosphors are stable oxides; therefore, their functions are semi-permanent and do not malfunction compared to mechanical guiding objects (i.e., RFID tags). Thus, our system appears to satisfy Requirement 4.

Requirement 5: The proposed system emits phosphors by optical excitation; therefore, unlike passive-type RFID tags, it does not require embedding batteries in the five locations. Thus, the proposed system appears to satisfy Requirement 5.

Requirement 6: Similar to RFID tags, manufacturers mass produce phosphors; therefore, they can be easily obtained. Thus, the proposed system appears to satisfy Requirement 6.

4.3 Safety measures

Fig. 11. Conditions for LED (Light Emitting Diode) emission.

Although we used laser light as the light source for optical excitation in the preliminary experiments, such a light source can affect the human eye. Thus, when we develop a prototype system, we will use multiple LED lamps as a light source because they have less risk of affecting the human eye and have lower power requirements. To prevent the unexpected emission of light from LEDs, we will emit light from LEDs only when the following conditions are satisfied:

(a) The cane is firmly grasped, which can be determined by embedding electrostatic capacity-type pressure sensors.

(b) The cane is positioned on the z-axis at an angle greater than a certain threshold (Fig. 11), which can be determined by embedding a gyroscope sensor and calculating the z-angle.

We used phosphor powders in our experiments, and they have a low risk of affecting the human body and the environment as they are stable oxides. However, we must carefully handle such a powder to avoid inhaling it and prevent it from entering into our eyes.

4.4 Optical modulation systems

For practical application, the system should distinguish the received light excited and generated by the light source without being affected by disturbance light in the indoor and outdoor environments. Currently, three optical modulation methods have been proposed (i.e., TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access), and CDMA (Code Division Multiple Access)). These methods require multiple light sources; thus, the cane's light source unit should have multiple light sources when adopting one of these methods. Each optical modulation method is described in the following.

The TDMA method controls whether each light source is on or off using extremely short time intervals. The time interval synchronizes with the light-receiving unit so that this unit can determine the light source unit. The size of the modulation and demodulation circuits is small because this method is simple; however, it is easily affected by disturbance light.

The FDMA method controls whether each light source is on or off using different frequencies for each light source. The light-receiving unit can determine the source of the received light because it knows each light source's modulation frequency, even when several light sources are simultaneously active. This modulation method is complex, and the size of the modulation and demodulation circuits

Table 2. Comparison of modulation and demodulation schemes.

	TDMA	FDMA	CDMA
Modulation and demodulation method	Simple	Complex	Simple
Size of modulation and demodulation circuits	Small	Large	Small
Influence degree of disturbance light	Large	Small	Extremely small

tends to be large; however, it is not easily affected by disturbance light.

The CDMA method controls whether each light source is on or off using different random numbers allocated to each light source. The light-receiving unit can determine the source of the received light because it knows each light source's random number, even when several light sources are simultaneously active. This modulation method is simple, and the size of the modulation and demodulation circuits tends to be small. In addition, it is not easily affected by disturbance light.

The characteristics of each method are listed in Table 2. As the CDMA method is superior than other methods, we will adopt it while developing our prototype system.

4.5 Reconstruction of the five locations

The five locations described in this study (guiding and warning blocks, pedestrian crossings, vehicle doorways, and vehicle floors) may need to be reconstructed due to deterioration and aging. In this case, construction companies should be careful to not spread massive amounts of phosphor particles contained in these places/objects to other locations because the system may falsely distinguish a roadway as a pedestrian crossing due to scattering of the phosphor particles.

To avoid such misrecognition, construction companies should choose appropriate methods to avoid the generation of massive amounts of dust during reconstruction. In addition, waste materials generated during reconstruction (e.g., removed braille blocks and cement lumps) should be disposed in landfills and not be reused as construction materials.

5. Conclusion

Visually impaired people can possibly experience stress and anxiety while walking on pedestrian crossings and vehicle doorways at train stations. In this study, we proposed a walking assistance system that provides

accurate information, i.e., the presence and type of braille blocks, using a cane and informs the visually impaired people about the contact of the cane to a guiding object at a given location.

In preliminary experiments, we prepared samples with epoxy resin and confirmed that we could observe the presence of phosphor even at a 5% weight ratio. We assessed the feasibility of the proposed system and found that it outperforms previous studies that are related to the incorporation of guiding objects, the CDMA method of modulating and demodulating light is more effective than the TDMA and FDMA methods, and using LEDs as a light source is safer for developing a prototype system. In the future, we plan to create a prototype using LED light sources and perform experiments in the indoor and outdoor environments for verifying the effectiveness of the proposed system.

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