PAPER *Special Section on Intelligent Transport Systems*

New Types of Markers and the Integration of M-CubITS Pedestrian WYSIWYAS Navigation Systems for Advanced WYSIWYAS Navigation Environments

Tetsuya MANABE[†a)], ***Member***, **Takaaki HASEGAWA**[†], ***Fellow***, **Takashi SERIZAWA**[††], **Nobuhiro MACHIDA**[††], **Yuichi YOSHIDA**[††], ***and*** **Takayuki FUJIWARA**[††], ***Nonmembers***

SUMMARY This paper presents two new types of markers of M-CubITS (M-sequence Multimodal Markers for ITS; M-Cubed for ITS) that is a ground-based positioning system, in order to advance the WYSIWYAS (What You See Is What You Are Suggested) navigation environments providing intuitive guidance. One of the new markers uses warning blocks of textured paving blocks that are often at important points as for pedestrian navigation, for example, the top and bottom of stairs, branch points, and so on. The other uses interlocking blocks that are often at wide spaces, e.g., pavements of plazas, parks, sidewalks and so on. Furthermore, we construct the integrated pedestrian navigation system equipped with the automatic marker-type identification function of the three types of markers (the warning blocks, the interlocking blocks, and the conventional marker using guidance blocks of textured paving blocks) in order to enhance the spatial availability of the whole M-CubITS and the navigation system. Consequently, we show the possibility to advance the WYSIWYAS navigation environments through the performance evaluation and the operation confirmation of the integrated system.

key words: *ground-based positioning, textured paving block, interlocking block, integrated navigation system, spatial availability*

1. Introduction

Demand for location-based services (LBS), such as pedestrian navigation systems (e.g., [1]–[4]), is increasing with widespread use of smartphones. It is said that approximately 70% of human activity is carried out indoors. Therefore LBS is needed not only outdoors, but also indoors, underground-malls and so on. Effectiveness and quality of LBS are affected by the performance of positioning subsystems that these services are using, so the precise and accurate positioning in all locations is required for providing high quality service.

Common positioning methods of mobile devices such as smartphones are global positioning systems (GPS), access points of wireless local area networks (WLAN), and mobile base stations (MBS). GPS is widely used as the first positioning social infrastructure, examples of LBS using them are Ref. [1], [4]. GPS provides the accurate smartphone positioning in the open sky, but it does not work properly inside buildings or in outdoor areas of multistory buildings and underground malls, because of reflection, shielding, and attenuation of radio waves from GPS satellites. Kojima et al. [5] evaluated the positioning performance of GPS equipped mobile phones in the west exit area of Shinjuku Station, and they reported that the average error was 79.95 m and the maximum error was 812.61 m. The authors investigated the positioning performance of smartphones in Sapporo City and surrounding areas [6]. As an example of the results, when they walked along sidewalks around Susukino Crossing, smartphone applications often estimated their position onto the wrong side of the road. The positioning performance like this is fatal to pedestrian navigation systems. Usui et al. [7] presented a pedestrian navigation system using real scenery photographs as a navigation media, and based on experiments they reported the evaluation result of influence of positioning accuracy on the understandability of navigation. It was shown that 10 m error of positioning is unsuited for pedestrian navigation systems using scenery images. The positioning method using the access points of WLAN is becoming the second positioning social infrastructure next to GPS and there is a lot of research related to the WLAN positioning (e.g., [8]–[14]). In order to provide the accurate and precise positioning performance stably, the establishment of database construction methods and robust positioning algorithm in considering changes in the received signal strength identifier (RSSI) are required. The positioning methods using MBS, e.g., [15], provide rough positioning, so that accurate positioning cannot be expected. In Ref. [6], the error generating mechanism of mobile device positioning for LBS was explained as three layer's consideration, that is, applications as the upper layer, mobile device platforms as the middle layer, and sub-platforms as the lower layer, such as the GPS, WLAN, and MBS. From the above, the mobile device positioning needs accurateness and preciseness in the areas that GPS cannot work properly, in particular, indoors, underground-malls, and outdoors near the buildings. Consequently, the existing common mobile device positioning methods cannot achieve accurateness, preciseness, and stability in indoors, underground-malls, and outdoors near buildings.

The authors proposed M-CubITS (M-sequence Multimodal Markers for ITS; M-Cubed for ITS) [16] that is one of the ground-based positioning systems, which can work

Manuscript received May 11, 2015.
Manuscript revised August 10, 2015.
[†]The authors are with the Division of Mathematics, Electronics and Informatics, Graduate School of Science and Engineering, Saitama University, Saitama-shi, 338-8570 Japan.
[††]The authors were in Saitama University, Saitama-shi, 338-8570 Japan.
a) E-mail: manabe@hslab.ees.saitama-u.ac.jp
DOI: 10.1587/transfun.E99.A.282

in buildings and outdoor near buildings where GPS cannot work well. M-CubITS arranges the binary bit stream of m-sequence as markers onto the ground, spatially. Users take a picture of the markers using their own camera-equipped mobile devices, then the system specifies the position and direction photographing. M-CubITS is one of the complementing methods of GPS positioning because M-CubITS specifies the position from the ground (GPS specifies the position from the space). So the combination of M-CubITS and GPS can realize the robust positioning social infrastructure. Before now, we proposed the markers painted on textured paving blocks and its recognizing method [17] and implemented it into mobile devices [18], [19]. The conventional systems [17]–[19] require the picture taken five or more textured paving blocks by user's camera for positioning. The markers of M-CubITS can be realized easily by painting to the textured paving blocks, but the system is restricted to places where the textured paving blocks are continuously laid. In order to realize the seamless positioning with complementing by M-CubITS, enhancing the spatial availability of M-CubITS is needed.

This paper presents two new types of markers of M-CubITS and the integrated system using three types of markers (two of them are the proposed markers, and the other is the conventional one) as one of the method to enhance the spatial availability of M-CubITS.

The rest of this paper is organized as follows: Sect. 2 describes M-CubITS pedestrian WYSIWYAS† navigation systems. Sections 3 and 4 present two new types of markers using warning blocks of textured paving blocks and interlocking blocks, respectively. Section 5 shows the integrated system both of the existing M-CubITS and the two new types of M-CubITS above.

2. M-CubITS Pedestrian WYSIWYAS Navigation System [16]

Figure 1 shows a use image of M-CubITS pedestrian WYSIWYAS navigation systems [16]. The navigation systems search a route between a user's location which is determined by M-CubITS and a user's destination which is input by the user, and guide the user intuitively by superimposed arrows onto the picture which has taken for the positioning of M-CubITS.

The conventional studies of the M-CubITS pedestrian WYSIWYAS navigation systems are as follows: The proposal of the marker using textured paving blocks (TPB) and the distinction method [17], implementation into feature phones and construction of the navigation system using textured paving blocks in Saitama University [18]. Figure 2(a) shows the markers using the textured paving blocks in Saitama University and the bit assignment of the markers is shown in Fig. 2(b). Referece [20] adds the audio guidance function to the feature phone application of Ref. [18], and shows that blind or visually-impaired people can use our system through the evaluation experiment targeted at the visually-impaired people. The terminal type system using the feature phone application [18] only works with the devices of NTT docomo and running the i-applications. Then, Ref. [20] has presented and constructed the mail server type system in order to realize the device and carrier independent system. Figure 3 depicts the system chart of the mail server type system. Users send the photo email of the markers to the mail server for navigation, then the mail server carries out positioning, route searching, generating navigation information, and sending the email of the navigation information to the users. Thus, the mail server type system can be used to anyone having the mobile devices equipping a camera and a function of sending/receiving photo emails.

Reference [21] has proposed the pedestrian navigation concept reference model, that is the tool for characterization and standardization of pedestrian navigation systems, and Ref. [19] has described the pedestrian navigation concept reference model based tripartite comparative study of M-CubITS pedestrian WYSIWYAS navigation systems processed in different places —terminal type (installing the application in mobile devices and processing the generation of navigation information in the devices, e.g., [18]), mail server type (a user sends the photo email to the mail server, then the server generates the navigation information and sends the emails of the navigation information to the user, e.g., [20]), and web server type (a user uploads the photo to the web server, then the server generates the navigation information and shows the navigation information as the webpage, this

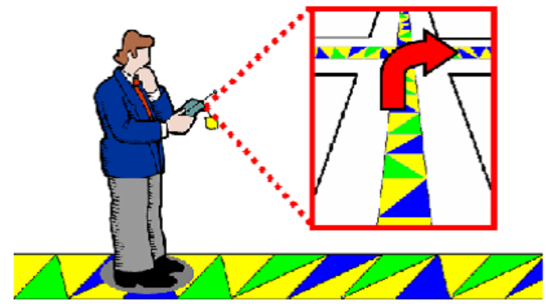
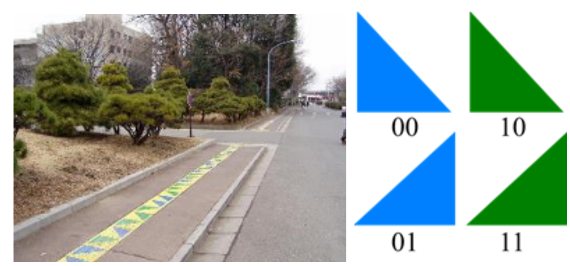


Fig. 1 An image of M-CubITS pedestrian WYSIWYAS navigation systems.



(a) Experimental environment. (b) Bit assignment.

Fig. 2 M-CubITS using the textured paving blocks in Saitama University.

†WYSIWYAS (What You See Is What You Are Suggested) is a fundamental design concept of human-machine interface of intuitive navigation. It corresponds to WYSIWYG (What You See Is What You Get) that is used by word processors.

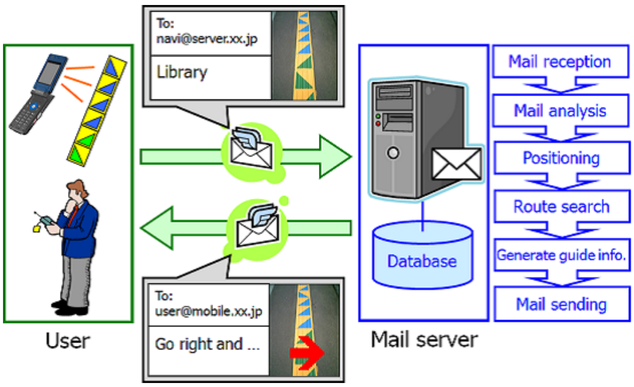


Fig. 3 System chart of mail server type M-CubITS pedestrian WYSIWYAS navigation system.

system has constructed in Ref. [19])—.

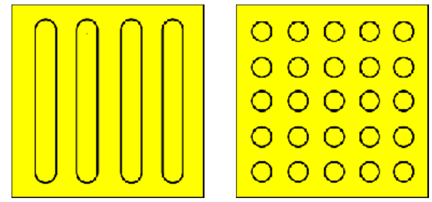
Our conventional systems [17]–[20] use the markers that continuously laid and painted textured paving blocks. So to provide the navigation service using our navigation systems in everywhere that GPS cannot work properly, to increase the number of installable places of M-CubITS is needed. This paper presents two new types, where the textured paving blocks are not laid continuously or there are no textured paving blocks, and integrates our systems using three types of markers (two of them are the proposed markers, the other is the conventional one) in order to enhance the spatial availability of M-CubITS and realize advanced WYSIWYAS navigation environments.

3. M-CubITS Using Warning Block of Textured Paving Blocks [20], [22]

Textured paving blocks have protuberances on their surface and assist pedestrians who are blind or visually-impaired to walk. There are two types of blocks (Fig. 4), guidance blocks (GB; Fig. 4(a)) and warning blocks (WB; Fig. 4(b)). The guidance blocks show directions of movement by stick-shaped protuberances. The blind/visually-impaired people confirm the shape of the protuberances by their foot soles or walking canes, so they can move. The warning blocks mean hazardous places by dome-shaped protuberances. The warning blocks are laid at, for example, the top and bottom of stairs, the foot of a ramp, the platform at a railway station, zebra crossings, and branch points of the guidance blocks. There are places that the warning blocks are laid without the guidance blocks (Fig. 5).

Here, paying attention to usage of textured paving blocks by the blind/visually-impaired people, they walk along the direction of the stick-shaped protuberances and almost never stop on the guidance blocks. In contrast, on the warning blocks, they stop once and confirm that there is no danger around them.

Most visually-impaired users use specific universal design type models, NTT docomo Raku-Raku Phone series†,



(a) Guidance block. (b) Warning block.

Fig. 4 Two types of textured paving blocks.

Fig. 5 An usage example of WB without GB.

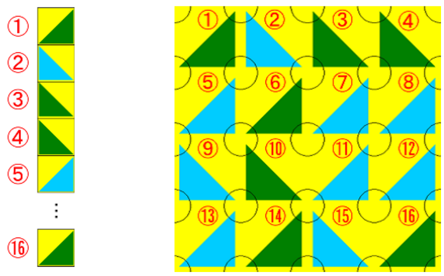
according to the survey on the use of mobile phones by visually-impaired persons [23]. The Raku-Raku Phone series are equipped with voice output of menu lists and emails as a standard function, so by the function, most visually-impaired people are using emails in everyday life. Furthermore, from the experimental result of Ref. [20], it has reported that visually-impaired persons can use our navigation system by operating their camera-phones. Consequently, the mail server type systems can realize the navigation environments providing navigation information using the wide use mobile devices that users are already owning. Moreover, if the blind/visually-impaired people use the Raku-Raku Phone that most of them already own, they can receive the audio guidance without an additional cost of purchase of devices.

On the other hand, the conventional systems using the textured paving blocks [17]–[20] did the marking without distinction of the guidance blocks or the warning blocks. However, in consideration of the places that the warning blocks are laid and the usage of the warning blocks by the blind/visually-impaired people, if the positioning by one warning block only can be realized, it will increase the number of available places that the navigation information can be provided, and it will improve the convenience of the navigation systems. In this section, in order to increase the number of available places of M-CubITS, we propose the new type of markers using the waring blocks of textured paving blocks and the positioning method using the marker. In addition, we evaluate the positioning performance of the proposed method.

3.1 Marker Arrangement Method for Warning Blocks

The conventional markers using textured paving blocks [17]–[20] have arranged one element per block. The new type marker using the warning blocks of textured paving

†https://www.nttdocomo.co.jp/english/product/easy_phone/ (Available: Aug. 1st, 2014)



(a) Guidance block. (b) Warning block.

Fig. 6 Marker element arrangement.

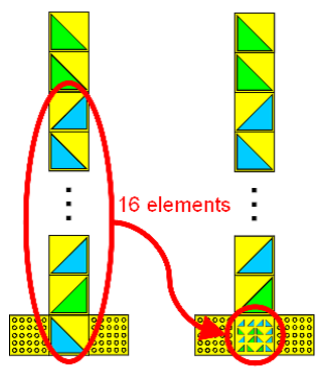


Fig. 7 Marker element arrangement from guidance blocks to warning blocks.

blocks arranges plural elements per block to realize positioning by the picture of one warning block. Here, in consideration of compatibility with the marker using guidance blocks, we arrange the elements onto warning blocks as follows:

- The miniaturized elements are arranged at each space surrounded by the dome-shaped protrusions (a total of 16 spaces).
- The arrangement order of the elements in the warning block is the same as the raster scan order of the image processing of the conventional markers (Fig. 6).
- A combination of the elements arranged into the warning block is the same as the combination of the markers of guidance blocks around the warning block (Fig. 7).

By arranging the elements of warning blocks like this, taking a photo of one warning block (0.3 m square) is the same effect as taking a photo of 16 guidance blocks (0.3 m×4.8 m). The conventional system [17]–[20] needs a picture that has been shot five or more guidance blocks for positioning, so the 11 elements of the marker using warning blocks can be used as redundant information. If the part sequence including the redundant information is collated with the m-sequence in the database, there's a possibility that the errors of positioning will reduce.

3.2 Positioning Method

Figure 8 shows a flow chart of positioning of M-CubITS using textured paving blocks, both guidance blocks and warning blocks.

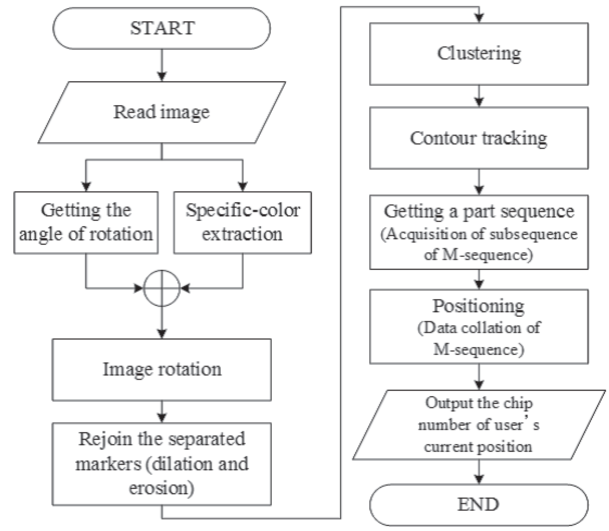


Fig. 8 Flowchart of positioning using textured paving blocks.

1) Getting the angle of rotation Rotate the image to align the direction of the markers with y-axis of the image for simplicity of the following processing. It includes detecting edges and border lines in lateral directions by a Sobel filter and a Hough transformation, and getting the angle of rotation θ that the border lines make with the x-axis of the image.

2) Specific-color extraction Extracting the colors of the markers (blue and green). Converting the color data of the input images from RGB (red, green, and blue) color space to HSI (hue, saturation, and intensity) color space.

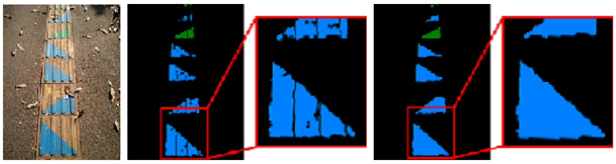
3) Image rotation Rotating the image after specific-color extraction $-\theta$ degrees have obtained in Procedure 1). This procedure makes simplify the following processes. This image rotation process always works if θ can be obtained correctly and unless input irregular images, e.g., horizontally long images, horizontal and/or vertical inverse images, and so on.

4) Rejoin the separated markers There is some failure in the specific-color extraction caused by the obstacles on the markers, e.g., fallen leaves and the edges of the stick-shaped protuberances of guidance blocks in the shadow. Figure 9(b) is an example image of separation of the marker's region and it will cause the positioning failure. Here, we apply the dilation† and the erosion†† to the specific-color extracted image in order to rejoin the separated markers. Figure 9(c) depicts the result of dilation and erosion.

†One of the morphological operations for adding pixels to the boundaries of objects in an image.†††

††One of the morphological operations for removing pixels on object boundaries.†††

†††Combining dilation and erosion is used for joining disparate elements, removing noise, and isolating individual elements.



(a) Input image. (b) Result of color extraction (before marker connection). (c) Result of marker connection.

Fig. 9 Process of image processing of textured paving blocks.

5) Clustering The conventional systems [17]–[20] determined the colors of the markers by fixed thresholds. It caused misjudgments of the colors and failures of positioning. Then, we introduce k-means clustering (two clusters; H_1, H_2) to the color determination.

- Hue of both clusters are less than 165 degrees. ⇒ H_1 and H_2 are categorized into green.
- Hue of both clusters are more than 195 degrees. ⇒ H_1 and H_2 are categorized into blue.
- Others ⇒ the cluster that the hue is larger is blue, another is green.

6) Contour tracking Getting each coordinate of the vertexes of triangles with the contour tracking.

7) Getting a part sequence Getting a part sequence of the m-sequence according to the shapes and the colors of the makers (Fig. 2(b)).

8) Positioning The part sequence is collated with m-sequence in the database. The system returns the chip number of m-sequence that the Hamming distance is minimum.

3.3 Positioning Performance Evaluation

We evaluate the positioning performance of the method proposed in 3.2. The experimental environment of the outdoors is the main street, approximately 300 meters long, of Saitama University. The illumination condition of the experiment is the daytime of either sunny or cloudy weather. 1008 guidance blocks and 13 warning blocks in the experimental environment are used as the markers. The installation locations of the markers are shown in Fig. 10. The experimental environment of the indoors is the West Exhibition Hall of Tokyo Big Sight. The illumination condition of there is that the all of the ceiling light (high intensity discharge lamp) are on steadily. 24 warning blocks set on the colored carpet are used as the markers. The installation locations of the markers are shown in Fig. 11. Examples of the indoor environments requiring pedestrian navigation systems are event sites, stations, airports, shopping malls, and so on. Typical characteristics of the environments are as follows: 1) stable illumination condition, 2) there are many people around the user. So we carried out the indoor experiment in the exhibition site of ITS World Congress Tokyo 2013 held at Tokyo Big Sight (West Hall 1 and 2) from Oct. 14th, 2013 to Oct. 18th, 2013. The camera equipped mobile devices for

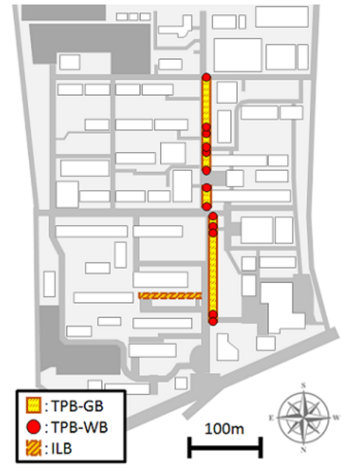
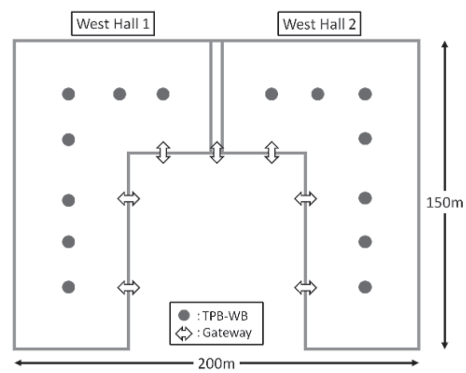
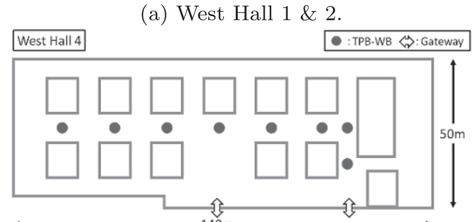


Fig. 10 Campus map of Saitama university.



(a) West Hall 1 & 2.



(b) West Hall 4.

Fig. 11 West exhibition hall of Tokyo big sight.

photographing are shown in Table 1. The photographed image resolution is QVGA (320×240 pixels). We use the m-sequence L=1023 generated from the stage number m=10 of the shift register, so the number of blocks required for positioning is more than five guidance blocks (if converted into length, it's 0.3 m×1.5 m or more) or one warning block (0.3 m square). The target images for the evaluation are as follows: 372 pictures of outdoor guidance blocks, 340 pictures of outdoor warning blocks, and 175 pictures of indoor warning blocks. All target images are with proper photographing conditions. Examples of the target images are shown in Fig. 12. We use three indexes for the evaluation —the positioning success rate (PSR; the percentage of the number of images that could be gotten the correct position against the total number of target images), the erroneous po-

Table 1 Camera phones for photographing of TPB.

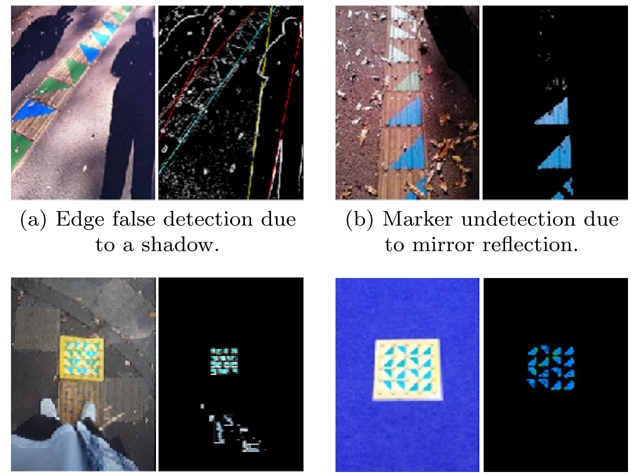
Type	Vendor	Model
Featurephone	Fujitsu	F-01B, F883iES
	Kyocera	W65K
	NEC	N-03A
	Sharp	930SH, 945SH, SH905i
	Sony	SO905iCS
Smartphone	Apple	iPhone 4
	Fujitsu	F-05D
	LG	L-01D
	Samsung	GT-N7000, Nexus S, SC-02B, SC-06D
	Sharp	A01, 003SH, 006SH, SH-12C
	Sony	SO-01B

(a) Outdoor GB. (b) Outdoor WB. (c) Indoor WB.

Fig. 12 Examples of target images of textured paving blocks.

Table 2 Result of positioning performance evaluation of TPB.

	Outdoor GB (conventional)	Outdoor WB (proposed)	Indoor WB (proposed)
PSR	80%	78%	89%
EPR	14%	4%	2%
PIR	6%	18%	9%



(a) Edge false detection due to a shadow. (b) Marker undetection due to mirror reflection. (c) Marker false detection due to clothes. (d) Color decision error to blue-colored carpet.

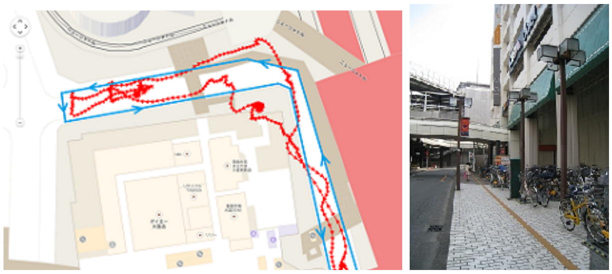
Fig. 13 Examples of positioning failure.

sitioning rate (EPR; the percentage of the number of images that were gotten the incorrect position against the total number of target images), and the positioning impossibility rate (PIR; the percentage of the number of images that could not be gotten the position against the total number of target images)—. The sum of EPR and PIR is the positioning failure ratio.

The result of the positioning performance evaluation is shown in Table 2. In the outdoor environment, the warning block typed marker has the almost same PSR as the guidance block typed marker. PSR of the warning block typed marker in the indoor environment is better than the outdoor environment because the illumination condition is stably. In addition, EPR of the warning block typed marker is lower than the guidance block typed marker because the warning block typed marker has the redundancy of 22 bits. When using the positioning results in the applications such as pedestrian navigation systems, low EPR of the positioning systems is not caused providing the wrong guidance information. The image examples of the failure positioning are shown in Fig. 13. The most frequently positioning failure cause of the outdoor guidance blocks was the edge erroneous detection (50% of 74 positioning failed images in total; Fig. 13(a)). The false detection of edges other than textured paving blocks, e.g., shadows and curbstones, caused either the false rotation of images or the false reading of markers' order. The next highest frequency failure is undetection of markers (32%; Fig. 13(b)). There were other causes as follows: the erroneous detection other than markers (11%) and the erroneous determination of markers' color (7%). The most frequently positioning failure cause of the outdoor warning blocks was the marker erroneous detection (42% of 76 positioning failed images in total; Fig. 13(c)). The false detection of color close to markers, e.g., clothes, shrubberies, and weeds. There were other causes as follows: the undetection of markers (38%), the edge erroneous detection (17%), and the erroneous determination of markers' color (3%). The most frequently positioning failure cause of the indoor warning blocks was the erroneous determination of markers' color (42% of 19 positioning failed images in total; Fig. 13(d)). There were other causes as follows: erroneous detection of markers (37%), erroneous detection of edges (11%), and the undetection of markers (11%). Consequently, PSR of the proposed marker using warning blocks is equal to or more than that of the conventional marker, so the spatial availability of M-CubITS is improved by using the warning blocks that enhance the available places in comparison with the conventional markers of guidance blocks only. Additionally, the low EPR of the proposed marker will be advantageous in providing the location information for pedestrian navigation systems, one of LBS, because it suppresses the wrong guidance caused by the erroneous positioning.

4. M-CubITS Using Interlocking Blocks [24], [25]

The original function of the textured paving blocks is to guide the visually-impaired people by the protuberances on the surface of the blocks. If the system comes into wide use, the textured paving blocks will become the social infrastructure for not only three-hundred thousand visually-impaired people in Japan but also all people, that is, it can increase



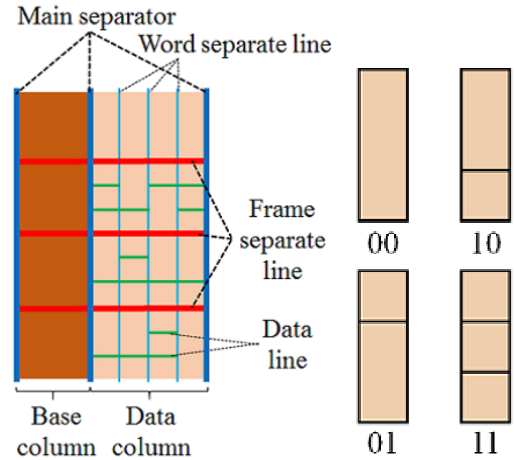
(a) Result of logged positions. (b) Experimental example.

Fig. 14 Positioning perfoemance investigation around the west exit of Omiya Station.

the social costs for the textured paving blocks. However, it is impossible to lay the blocks onto everywhere even if the cost problem of the blocks can be solved, for example, in a case that the blocks can not be laid physically. Moreover, the textured paving blocks at wide spaces, e.g., plazas, parks, and so on, are often laid at only a part of flow line of pedestrians. And also, there are few signboards for navigation in such a place. Furthermore, in front of the station that there are high-rise buildings, GPS cannot often realize accurate positioning. Figure 14(a) shows the result of the positioning performance investigation around the west exit of Omiya Station using the location information logger application [6]. In Fig. 14(a), the blue line is the path we have walked and the red one is the path specified by GPS on smartphones. The logged positions are off from the actual positions, so it isn't good enough to use by LBS such as pedestrian navigation systems. However, a lot of interlocking blocks are used there, Fig. 14(b) is an example around the west exit of Omiya Station. In this section, in order to improve the spatial availability of M-CubITS, we consider the interlocking blocks that used for pavements of plazas, parks, and sidewalks to use as the new type of the marker for increasing the number of available places of M-CubITS.

4.1 Arrangement of Interlocking Blocks

M-CubITS of the textured paving blocks represented the binary bits by colors and shapes. M-CubITS of interlocking blocks proposed in this paper represents the binary bits by shapes (Fig. 15(b)). An example of arrangement of interlocking blocks is shown in Fig. 15(a). The data column represents the binary bits of m-sequence and the base column is used for determining the photographing direction. The main separators divide the base column, the data column, and other regions. The word separate lines divide the data column to four sub-columns. The frame separate lines divide the blocks of the base column. The data lines divide the blocks of the each sub-column. After here, we call these lines and separators to boundaries. The blocks of the base column are squares, e.g., 30×30 cm. When the data column is right side of the base column, the binary bit of m-sequence is arranged in increasing order from left to right, front to back.



(a) Definitions of blocks and boundaries. (b) Bit assignment.

Fig. 15 Marker arrangement of interlocking blocks.

Here, we try to compare M-CubITS using the textured paving blocks and using the interlocking blocks. In the case specifying the position and the direction of users from 300 m total length, M-CubITS using the textured paving blocks needs to take a picture of more than five markers (equal to 1.5 m) and to get 10 bit, that are the code length $L = 2^{10} - 1 = 1023$ bit. On the other hand, M-CubITS using the interlocking blocks needs to take a picture of more than two markers (equal to 0.6 m) and to get 12 bit including one redundancy bit, that are the code length $L = 2^{11} - 1 = 2047$ bit. In another case, if each system requires the markers within the range 1.5 m ($L = 2^{10} - 1 = 1023$ bit) for positioning, the maximum positioning distance of M-CubITS using TPB is 300 m, but ILB is approximately 40000km ($L = 2^{27} - 1 = 134217727$ bit).

4.2 Positioning Method

Figure 16 shows a flow chart of positioning of M-CubITS using the interlocking blocks that have described 4.1. An example of the process is shown in Fig. 17.

1) Edge detection Detecting edges of the lateral direction with the Prewitt filter in order to detect the boundaries.

2) Main separator and word separate line detection Detecting the main separators and the word separate lines from the result of the edge detection. The main separators of the both sides of the data column have higher edge strength than other boundaries' edge strength, so that the two main separators can be detected stably. Moreover, the widths of each column (base column and data column) and each data block are known numbers, therefore other boundaries (another main separator and word separate lines) can be estimated using the width of the data column. In other words, if the width of the data column is $4d_1$, the width of the base column is $3d_1$ and the width of each data block is d_1 (Fig. 18). The estimation method is as per

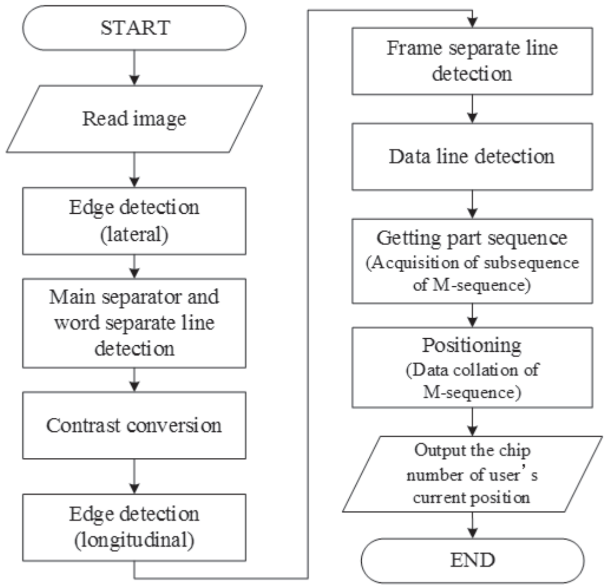
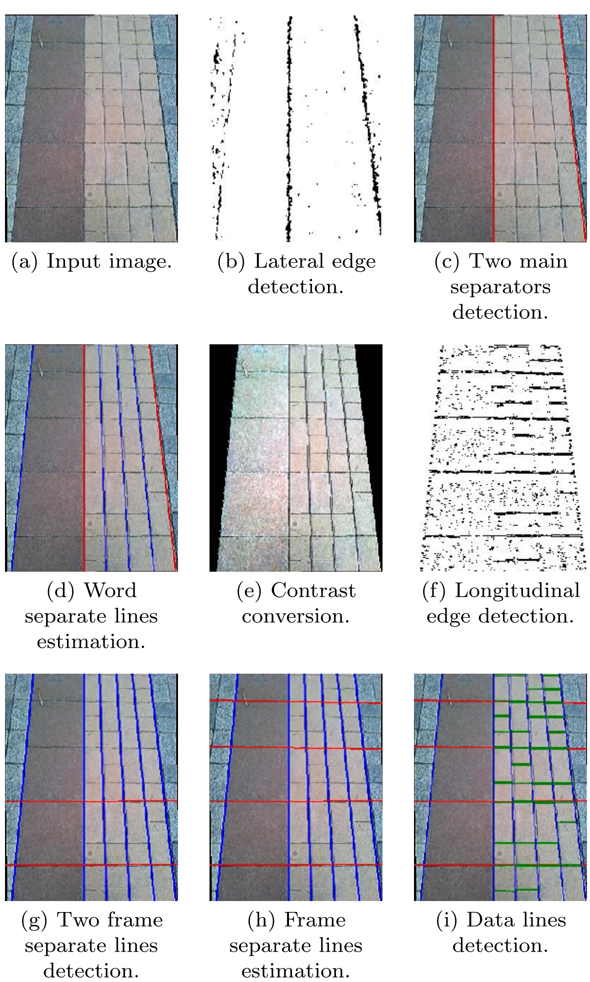


Fig. 16 Flowchart of positioning using interlocking blocks.



(a) Input image. (b) Lateral edge detection. (c) Two main separators detection. (d) Word separate lines estimation. (e) Contrast conversion. (f) Longitudinal edge detection. (g) Two frame separate lines detection. (h) Frame separate lines estimation. (i) Data lines detection.

Fig. 17 Process of image processing of interlocking blocks.

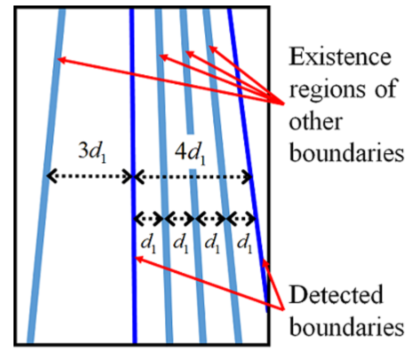


Fig. 18 Relation of lines of longitudinal direction.

the following. First, detecting the both sides of the boundaries of the data column with the Hough transformation. Then, estimating existence regions of other boundaries using that the width of the data column is $4d_1$. Last, detecting all boundaries in the existence regions with the Hough transformation. Herewith, the procedure can prevent the false detection and the undetection of main separators and word separate lines.

3) Contrast conversion The detection of the boundaries of longitudinal direction is performed next, but the edge strength of the longitudinal direction is lower than the lateral direction because the same color blocks are being arranged in the longitudinal direction. Therefore, in order to reduce possibility of failure of the following processing and positioning, the stable boundary determination performance is needed. To do so, the stable edge detection performance is required. Here, the input image has been divided to the three regions —the base column, the data column, and the boundaries (the main separators and the word separate lines)— by the procedure 2), that is, the brightness distributions of each region can be acquired. In addition, the brightness distributions of each region are generally the same in both the lateral direction and the longitudinal direction, it will be possible to detect the boundaries high precision by converting the contrast of the image (shifting the distribution of the boundaries to low and the distribution of the columns to up). The contrast conversion process is the following. First, generating the brightness distributions of the boundaries and the columns respectively using the result of the procedure 2). Second, calculating the average brightness of the boundaries $\overline{I_B}$, the average brightness of the columns $\overline{I_C}$, the standard deviation of the brightness of the boundaries σ_B, the standard deviation of the brightness of the columns σ_C. Third, determining the transforming region $[I_{min}, I_{max}]$, where $I_{min} = \overline{I_B} - 2\sigma_B$ and $I_{max} = \overline{I_C} + 2\sigma_C$. Last, converting the brightness from $[I_{min}, I_{max}]$ to $[0, 255]$ linearly using Eq. (1). Figure 19 shows an example of the brightness distribution before/after the contrast transformation.

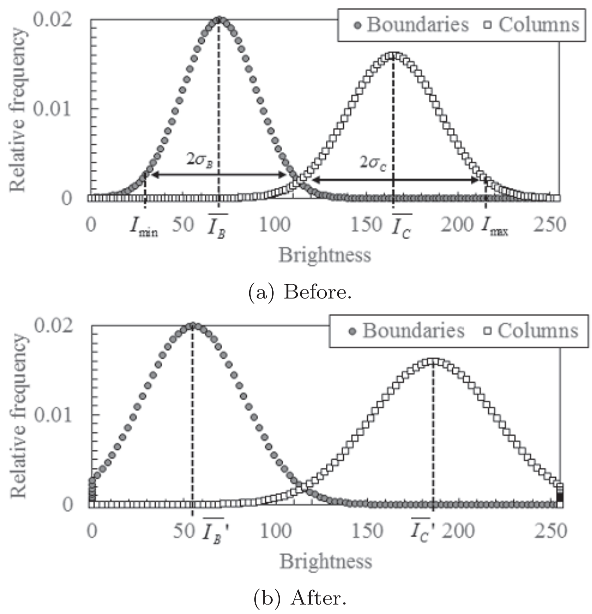


Fig. 19 An example of brightness distribution before/after contrast conversion ($\overline{I_B}=70$, $\overline{I_C}=165$, $\sigma_B=20$, $\sigma_C=25$, $I_{min}=30$, $I_{max}=215$).

$$I' = \begin{cases} 0 & (0 \le I < I_{min}) \\ 255 \times \frac{I - I_{min}}{I_{max} - I_{min}} & (I_{min} \le I \le I_{max}) \\ 255 & (I_{max} < I \le 255) \end{cases} \quad (1)$$

4) Edge detection Detecting edges of the longitudinal direction with the Prewitt filter in order to detect the boundaries.

5) Frame separate line detection The base column blocks are squares and the length of a side d_2 has been determined in the procedure 2), that is, $d_2 = 3d_1$. Therefore, most frame separate lines can be estimated with high precision by a few frame separate lines having the high edge strength and the projection-transformed image (Fig. 20). The estimation method is as per the following. First, detecting the frame separate lines having the high edge strength (the green lines in Fig. 20) with the Hough transformation. Second, projection-transforming the image to arrange the both sides of the main separators of the base column in parallel. Third, estimating existence regions of other frame separate lines (the yellow lines in Fig. 20) using d_2. Last, detecting all frame separate lines in the existence regions with the Hough transformation. Herewith, the procedure can prevent the false detection and the undetection of frame separate lines. The projection-transformation works well if the frame separate lines having the high edge strength can be detected correctly and unless input irregular images, e.g., horizontally long images, horizontal and/or vertical inverse images, and so on.

6) Data line detection Detecting the data lines that exist between adjacent two frame separate lines from the result of the procedure 5).

7) Getting a part sequence Getting a part sequence of the m-sequence according to the shapes of the makers (Fig. 15(b)). If the data column is right side of the base column, the part sequence is read in increasing order from left to right, front to back. If the data column is left side of the base column, the part sequence is read in increasing order from right to left, back to front.

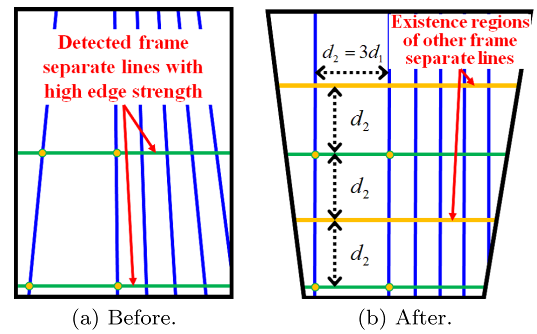


Fig. 20 Projection transformation of interlocking blocks.

8) Positioning The part sequence is collated with m-sequence in the database. The system return the chip number of m-sequence that the Hamming distance is minimum.

In this section, we used the Prewitt filter for the edge detection. The edge strength of the Prewitt filter is weaker than the Sobel filter used for the edge detection of textured paving blocks of Sect. 3. However, the Sobel filter may erroneously detect small stones or inequalities of the road. On the other hand, the required edge detection performance for the marker using interlocking blocks is higher than the marker using textured paving blocks, especially low false detection, because the edge detection results of textured paving blocks are only used for the image rotation, however, the edge detection results of interlocking blocks are used for generating histograms, dividing blocks, and so on. Therefore, the proposed positioning method uses the Prewitt filter that has low false detection performance of the edge of markers. To improve the undetection performance instead, the contrast conversion process was adopted to the proposed positioning method. Both filters need to scan all the pixels in the target image, so the processing time and the ease of introduction are invariant.

4.3 Positioning Performance Evaluation

We evaluate the positioning performance of the positioning method described in 4.2. Here, we use the pictures of the interlocking blocks laid the length of approximately 70 m in outdoors of Saitama University (Fig. 10 and Fig. 21). The camera equipped mobile devices for photographing are shown in Table 3. The photographed image resolution is QVGA (320×240 pixels). The number of blocks required for positioning are that the marker of interlocking blocks is three or more rows (if converted into length, it's 0.7×0.9 m or more). We use three indexes for the evaluation same as 3.3 —PSR, EPR, and PIR—. The target of images for the

Fig. 21 Experimental environment of interlocking blocks in Saitama University.

Table 3 Camera phones for photographing of ILB.

Type	Vendor	Model
Featurephone	NEC	N-06A, N905i, N906iμ
	Panasonic	P-04A, P704iμ
	Sharp	812SH, 816SH, 930SH, SH901iS
	Sony	SO905iCS
	Toshiba	814T

(a) Daytime on sunny day. (b) Daytime on rainy day. (c) Nighttime under Na-light.

Fig. 22 Examples of evaluation images of ILB.

evaluation are as follows: 234 pictures in the daytime on sunny/cloudy day, 73 pictures in the daytime on rainy day, and 118 pictures in the nighttime under the sodium light (below is called Na-light). All target images are with proper photographing conditions. Examples of the target images are shown in Fig. 22.

The result of the positioning performance evaluation is shown in Table 4. EPR under the all illumination condition were 0%. The image examples of the failure positioning are shown in Fig. 23. The most frequently positioning failure cause of the daytime on sunny/cloudy weather was the undetection of longitudinal boundaries including the data lines and the frame separate lines (58% of 24 positioning failed images in total). The reason of failure is the low edge strength of the boundaries of the longitudinal directions. There were other causes as follows: undetection of the main boundaries (21%) and erroneous detection of longitudinal boundaries (21%). The most frequently positioning failure cause of the daytime on rainy weather was the undetection of main separators (75% of 12 positioning failed images in total). When it started to rain, the block surface was discolored by the rainwater penetration as in the Fig. 23(b). There were other causes as follows: erroneous detection of

Table 4 Result of positioning performance evaluation of ILB.

	Daytime		Nighttime
	sunny/cloudy	rainy	(Na-light)
PSR	90%	84%	64%
EPR	0%	0%	0%
PIR	10%	16%	36%

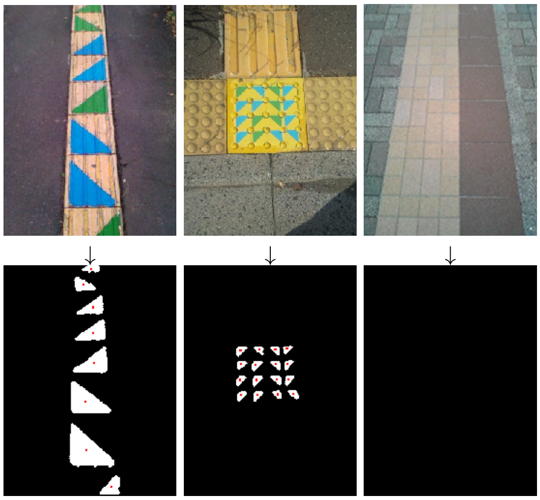
(a) Daytime on sunny day. (b) Daytime on rainy day. (c) Nighttime under Na-light.

Fig. 23 Examples of positioning failure images of ILB.

the data lines (17%) and undetection of the data lines (8%). The most frequently positioning failure cause of the nighttime under the Na-light was the undetection of longitudinal boundaries (63% of 41 positioning failed images in total). In the nighttime, the edge strength became low compared with the daytime because of the insufficient brightness. There were other causes as follows: erroneous detection of longitudinal boundaries (22%), undetection of main separators (10%), and erroneous detection of main separators (5%). Consequently, the proposed marker using the interlocking blocks improves the spatial availability of M-CubITS, because the blocks also can be used for positioning other than the textured paving block typed markers. Additionally, the erroneous positioning did not occur on the proposed method using the interlocking block typed markers and it will be advantageous in providing the location information for pedestrian navigation systems.

5. Construction of Integrated System with Marker-Type Automatic Identification

Up until the previous section, we have proposed two new types of markers of M-CubITS and the positioning method using them. Laying the three types of markers of M-CubITS including the conventional marker [17]–[20] effectively will increase the number of available places of M-CubITS and navigation systems. However with the present condition, the positioning systems work individually, that is, users should identify the markers or select the operation procedures. Then, in order to improve the spatial availability of the whole M-CubITS, the system has to identify the markers that users have photographed automatically. In this section, we introduce the automatic marker-type identification method to adapt the positioning method for each marker. Moreover, we construct the integrated system using the introduced method.



(a) TPB-GB. (b) TPB-WB. (c) ILB.

Fig. 24 Examples of color extraction for merker-type identification.

Table 5 Marker-type identification rate.

MarkerType	Cond.	Img.	Marker-type identification rate TPB-GB	TPB-WB	ILB
TPB-GB	Outdoor	372	96.0%	4.0%	0%
TPB-WB	Outdoor	340	0.3%	99.7%	0%
	Indoor	175	0%	100%	0%
ILB	Daytime (Sun/Cloud)	234	0%	0%	100%
	Daytime (Rain)	73	0%	0%	100%
	Nighttime	118	0%	0%	100%

5.1 Marker-Type Automatic Identification Method

To identify the three types of markers automatically, we focus on the color and the installation intervals of the markers. In other words, the markers of the textured paving blocks are including the color of green or blue, but the markers of the interlocking blocks are not including such color. Moreover, the installation intervals of the markers of the guidance blocks are wider than the intervals of the markers of the warning blocks. Then, we propose the automatic marker-type identification method using these characteristic as follows: First, the color of green and blue is extracted from the input images as marker regions. Second, each centroid of the marker regions is calculated. Third, the Euclid distances between each two centroids are calculated and the centered marker that minimize the sum of all distance between each two centroids is selected. Last, calculating the average distance $\overline{d}$ of each distance from the centered marker to each nearest five markers and discriminating the markers as follows: A case of $\overline{d} > \frac{1}{8}\sqrt{w^2+h^2}$ is the guidance blocks, a case of $\frac{1}{40}\sqrt{w^2+h^2} < \overline{d} \leq \frac{1}{8}\sqrt{w^2+h^2}$ is the warning blocks, and another case is the interlocking blocks. Where, w is the width of the input image, h is the height of the input image, and $\sqrt{w^2+h^2}$ is the length of the diagonal line of the input image. Figure 24 shows examples of the photographed images of each marker and results of the image processing for the automatic marker-type identification. Figures 24(a), (b) include the marker regions of green or blue, so the regions have been painted white and the centroids have been dotted by red. On the other hand, Fig. 24(c) does not include the marker regions of green or blue, so the image processing result has not been painted anything.

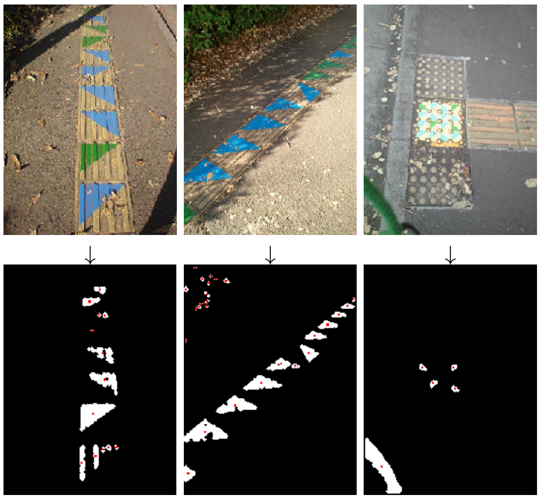
5.2 Marker-Type Identification Performance Evaluation

We evaluate the marker-type identification performance described in 5.1. Here, the target images for the evaluation are all 1312 images that have used in the positioning performance evaluation in 3.3 and 4.3. The details of the images are as follows: 372 images of TPB-GB (everything is in outdoors), 515 images of TPB-WB (outdoor: 340, indoor: 175), and 425 images of ILB (daytime on sunny/cloudy day: 234, daytime on rainy day: 73, nighttime under the Nalight: 118). Examples of the target images are shown in Fig. 12 and Fig. 22. We use the marker-type identification rate (MIR; the percentage of the number of images that were identified each marker against the total number of each target marker images) as the index for the evaluation.

A performance evaluation result of the marker-type identification rate is shown in Table 5. MIR of ILB was 100%. MIR of TPB (TPB-GB and TPB-WB) were not 100% but it was a close value to 100% and the erroneous identification to ILB was none. The image examples of the failure identification are shown in Fig. 25. The marker-type identification failure cause was as follows: undetection and separation of markers (69%; Fig. 25(a)), marker undetection (13%), marker separation (6%), and erroneous detection of markers (6%; Fig. 25(b)), undetection and erroneous detection of markers (6%; Fig. 25(c)). As mentioned in 3.1, the markers of the textured paving blocks have compatibility and use the same positioning algorithm. So the erroneous identification —TPB-GB→TPB-WB or TPB-WB→TPB-GB— does not affect the positioning and navigation systems including the automatic maker-type identification method. This means that the marker-type identification success rates of the textured paving blocks (including both of guidance blocks and warning blocks) and the interlocking blocks are 100%.

5.3 Construction of Integrated System

In this section, we construct the integrated navigation systems including the automatic marker-type identification method. As mentioned above, there are three types of the M-CubITS pedestrian WYSIWYAS navigation systems, we construct the integrated system using the mail server typed system in this paper considering the versability of the number of mobile devices. The objective area is in Saitama University where all of three types of markers has been installed (Fig. 10; TPB-GB are 1008 blocks (approximately 300 m long), TPB-WB are 13 blocks, and ILB are approximately 70 m long). Users send the email including the destination information and the image of the markers to the



(a) Marker undetection & separation. (b) Marker false detection. (c) Marker false detection & undetection.

Fig. 25 Examples of merker-type identification error images.

(a) Sent mail. (b) Sent image. (c) Received mail. (d) Received image.

Fig. 26 Integration system working example#1: a case of textured paving blocks.

mail server equipping the automatic marker-type identification function. The mail server distinguishes the marker-type of the attached image using the proposed identification method. Then, the server calls the function for the textured paving blocks or the interlocking blocks to carry out the positioning process. Moreover, the called process specifies user's location and sends the email including the navigation information to the user. Thus, the integrated system can be used without distinguishing the marker-types by users, that is, the users are not required to identify the marker-type when they use the navigation system. Figure 26 and Fig. 27 are the working examples of the constructed integrated system.

5.4 Performance Evaluation of Integrated System

We evaluate the positioning performance of the integrated system that have constructed in 5.3. The evaluation condition is in daytime on sunny/cloudy day in outdoor area of Saitama University. The target images satisfied the condition are extracted from the previous evaluations in 3.3, 4.3,

(a) Sent mail. (b) Sent image. (c) Received mail. (d) Received image.

Fig. 27 Integration system working example#2: a case of interlocking blocks (the destination mail address of (a) is the same as Fig. 26(a)).

and 5.2, that is, 372 images of TPB-GB (e.g., Fig. 12(a)), 340 images of TPB-WB (e.g., Fig. 12(b)), and 234 images of ILB (e.g., Fig. 22(a)). The evaluation indexes are also the same as the previous evaluations in 3.3 and 4.3, that is, PSR, EPR, and PFR. Result of the positioning performance evaluation is as follows: PSR is 82%, EPR is 7%, and PIR is 11%. As mentioned in 5.1, the integrated system carries out the marker-type identification of the image sent from a user, then the input image is taken over to the each positioning algorithm according to the identification result. In other words, the positioning performance of the system depends on the marker-type identification performance and the positioning performance for each marker. According to 5.2, the marker-type identification success rate was 100%, that is, the positioning performance of the integrated system depends on the positioning performance of each marker. The spatial availability of the integrated systems improves as compared with the conventional system using the guidance blocks of textured paving blocks. Additionally, high PSR and low EPR are advantageous in pedestrian navigation systems.

The result understandably depends on the installation ratio of the markers and the rate of utilization by users. The utilization rate by the users is presumed to be the same, because the PSR of the three types of markers has been almost the same from the results of the experiments above. Therefore, we investigate the installation ratio of the blocks available as the marker in actual environments. Here, we select the following three areas: Saitama University[†], Omiya Station[††], and Minami-Yono Station[†††]. The investiga-

[†]The whole area and all buildings of Okubo Campus of Saitama University. The size of the area was about 700 meters north to south, and about 400 meters east to west. There are 49 buildings in the campus.

[††]The area within the radius of 200 meters from the each exit of the station as an example of the large-scale station. The number of average daily passengers in FY2012 was approximately 330 thousand people[††††]. The available railway routes are 13.

[†††]The area within the radius of 200 meters from the each exit of the station as an example of the medium-scale station. The number of average daily passengers in FY2012 was approximately 15 thousand people[††††]. One railway route is available.

[††††]Statistical yearbook of Saitama prefecture FY2012 (in

Table 6 Results of positioning performace evaluation of integrated system.

	Number of blocks			Positioning Perform.		
	TPB-GB	TPB-WB	ILB	PSR	EPR	PIR
Saitama Univ. (Exp.)	1,008	13	233	82%	7%	11%
Saitama Univ. (Whole)	1,854	73	2,545	86%	6%	8%
Omiya Sta.	8,411	178	556	81%	13%	6%
Minami-Yono Sta.	776	61	115	81%	12%	7%

tion method is as follows: First, counting the number of the blocks on the all passages, where pedestrians can walk, in the each target area. If the regions expanding spatially such as plazas are counted the number of blocks on main flow lines. TPB-WB are counted as “spot” that is the group that several blocks are laid together as in Fig. 5. The results of the investigation is shown in Table 6. It is the weighted average by the number of blocks in the each target area. PSR is over 80% in all environments and it is practically sufficient performance for our navigation system.

Next, we consider about the accuracy and the precision of positioning. M-CubITS specifies the chip number of m-sequence as the user’s position, in other words M-CubITS does not have the mechanism for evaluating the accuracy. The precision of the system depends on the photographing method of the markers, that is, the depression angle. If the angle is large, the markers around user’s feet are taken and the precision becomes high. On the other hand, if the angle is small, the photographed markers are on a faraway place from users and the precision becomes low, but the precision is up to 2 m in consideration of the photographing limit of the number of markers and the size by M-CubITS. It is practically sufficient performance for our navigation system.

Furthermore, we consider the processing time on the server. The processing time includes the time of the marker-type identification, the time of the positioning of TPB, and the time of positioning of ILB. The time of the marker-type identification is the time period between the arrival of a user’s email and the completion of the marker-type identification. The time of the positioning of TPB or ILB is the time period between the completion of the marker-type identification and the completion transmitting an email including navigation information to the user. The results of the processing time (average and standard deviation) were as follows: The marker-type identification process was 171±91 msec, the positioning process of TPB was 1775±38 msec, and the positioning process of ILB was 3222±60 msec. The server’s specification is shown in Table 7. According to Ref. [19], the response time for users of our mail server system includes the processing time on the server and the communication time of two emails. The communication time was 12500±3030 msec using a smartphone (Samsung Nexus S) and wireless LAN (IEEE 802.11g) under the normal communication traffic when the outgoing and incoming average communication speeds are 1 Mbps and 3 Mbps respectively [19]. The communication time occupies most of the response time in the mail server system and

Japanese). http://www.pref.saitama.lg.jp/site/a310/a310a2013.html (Availabale: Aug. 1st, 2014)

Table 7 Server specification.

CPU	Intel Core 2 Duo E8500 3.16 GHz
RAM	4.00 GB
OS	Windows 7 Professional 64 bit
Software	Xmail 1.27 XMailCFG 2.41c ActivePerl 5.12.3 Ruby 1.9.2

the processing time of the marker-type identification process is less than 10% against that of the positioning process. Consequently, the proposed identification method does not affect on the processing time of the integrated system.

6. Conclusion

This paper has presented two new types of markers of M-CubITS in order to advance the WYSIWYAS navigation environments. One of the new markers has used warning blocks of textured paving blocks that have been often at important points as for pedestrian navigation, for example, the top and bottom of stairs, branch points, and so on. The other has used interlocking blocks that have been often at wide spaces, e.g., pavements of plazas, parks, sidewalks and so on. Furthermore, we have constructed the integrated pedestrian navigation system equipped with the automatic marker-type identification function of the three types of markers (guidance blocks, warning blocks, interlocking blocks) in order to enhance the spatial availability of the whole M-CubITS and the navigation system. Consequently, we have shown the possibility to advance the WYSIWYAS navigation environments through the performance evaluation and the operation confirmation of the integrated system.

As future work, we will improve the positioning performance of M-CubITS using the textured paving blocks by the pattern recognition with a constraint condition of the triangular shape of the markers. We will make improvements on the positioning performance of M-CubITS using the interlocking blocks by improving the data line detecting processing. Moreover, sophisticating error correcting processing as a common future work of the positioning method of M-CubITS, and evaluating the integrated M-CubITS pedestrian WYSIWYAS navigation systems from a viewpoint of the navigation performance.

Acknowledgments

A part of this work was supported by JSPS KAKENHI Grant Numbers 20500085 and 23500111. The authors would like to thank Mr. Koji Kawamata, Mr. Yasuo Kitamoto, and Mr. Yasuo Wada of Sumitomo Osaka Cement Co., Ltd. for their cooperation of M-CubITS using interlocking blocks. We were supported from The Japan Organizing Committee of ITS WORLD CONGRESS TOKYO 2013 for the experiment in Tokyo Big Sight. We obtained useful advice about behavior of visually-impaired people from Professor Katsumi Tokuda of University of Tsukuba, Associate

Professor Tomomi Mizuno of University of Tsukuba, and Associate Professor Arisa Nishidate of University of Toyama. We are also thankful to the members of WYSIWYAS Navigation Consortium (WyNC) for the valuable advice.

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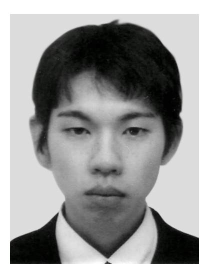

Tetsuya Manabe received his B.E., M.E., and Ph.D. degrees in Electrical and Electronic Systems from Saitama University, in 2006, 2008, and 2012 respectively. He has been an assistant professor with the Division of Mathematics, Electronics and Informatics, Graduate School of Science and Engineering, Saitama University since 2013. His current research interest is IT based systems innovation for human's mobility sophistication, in particular, realizing information society infrastructure in real world, e.g., pedestrian navigation systems including seamless positioning and information systems for lifesaving in time of disaster. He is a member of IEEE and IPSJ.

Takaaki Hasegawa received his B.E. and M.E. and Ph.D. degrees in Electrical Engineering from Keio University in 1981, 1983, and 1986, respectively. He joined the Faculty of Engineering at Saitama University in 1986. He has been a Professor of Division of Mathematics, Electronics and Informatics, Graduate School of Science and Engineering, Saitama University since 2006. During 1995–1996, he was a visiting scholar at the University of Victoria. His research interests include mobility and economic vitalization systems innovation based on Quality of Spatial Comfort (QoSC) with Information and Communication Technology (ICT) as well as Intelligent Transport Systems (ITS) in particular, applications, platforms, architecture, communications, positioning, and HMI techniques for ITS. He was a chair of the technical research group on ITS as well as on Spread Spectrum Technology (SST) at the IEICE. He was also a member of the board of governors of IEEE ITS Society. Now he is a fellow of IEICE, and a member of IEEE, the International Association of Traffic and Safety Sciences (IATSS), the Information Processing Society of Japan (IPSJ), the Society of Automotive Engineers of Japan (JSAE), and the Japan Society of Applied Science.

Takashi Serizawa received his B.E. and M.E. degrees in Electrical and Electronic Systems from Saitama University, in 2008 and 2010 respectively. He engaged in a study of the navigation system using textured paving blocks.

Nobuhiro Machida received his B.E. degree in Electrical and Electronic Systems from Saitama University, in 2009. He engaged in a study of the navigation system using interlocking blocks.

Yuichi Yoshida received his B.E. and M.E. degrees in Electrical and Electronic Systems from Saitama University, in 2009 and 2011 respectively. He engaged in a study of the positioning performance improvement of M-CubITS using interlocking blocks.

Takayuki Fujiwara received his B.E. and M.E. degrees in Electrical and Electronic Systems from Saitama University, in 2012 and 2014 respectively. He engaged in a study of the positioning performance improvement of M-CubITS using textured paving blocks.