# Stabilization Method for Floor Projection with a Hip-Mounted Projector

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**ABSTRACT**

These days, location information services such as map guiding or location awareness are used privately or in business. These services are often used even while moving with cell phones or PDA. However, these mobile terminal devices restrict the use of one hand and demand that a user keep a close watch on the small display. It makes the user difficult to use it when he/she holds or carries some materials in both hands. Also, it may complicate indication of information considering embodiment.

To solve the above issues, we propose to project information on the ground from a hip-mounted projector. Furthermore, we propose a projection stabilization method which makes the user easier to look information while walking. Specifically, firstly we detected dominant moving components of the projector which affect viewability of the user by analysis using a simulator. After that, in view of the fact, we implemented an original stabilization method which negates the influence of dominant rotational movement with a gyroscope. As a result of usability test, we confirmed that the proposed stabilization method improved the user viewability.

**Index Terms:** H.5.2 [Information Interfaces and Presentation]: User Interfaces—Theory and methods; I.4.8 [Image Processing and Computer Vision]: Scene Analysis—Sensor fusion;

## 1 INTRODUCTION

Due to the prevalence of positioning technology by use of GPS or Wi-Fi, demands for location information services are increasing [11]. For example, there are some services such as map guiding for an individual user or location awareness which enables improvement of work efficiency in research facilities or warehouses. Since these services are often used by a user who is moving, it generally provides information to him/her by means of small liquid crystal displays of mobile interface such as cell phones or PDA. However, these terminal devices are based on the premise that a user holds the device in one hand and keeps a close watch on the display. It makes a user who holds or carries some materials in both hands difficult to use it. Also, it may complicate indication of information which considers embodiment. For instance, destination annotation, such as arrowhead, based on the user's posture is difficult to represent a exact direction.

To cover these shortcomings of mobile interface, other studies on information browsing method have previously been proposed. Although HMD or clip-on display [18] [17] can realize hands-free, it makes a user feel fatigue and discomfort in long period of use. To solve this problem, many researches about projecting information on environmental objects or body by use of wearable mobile projector have been proposed. Blasko [3] depicted augmented-display

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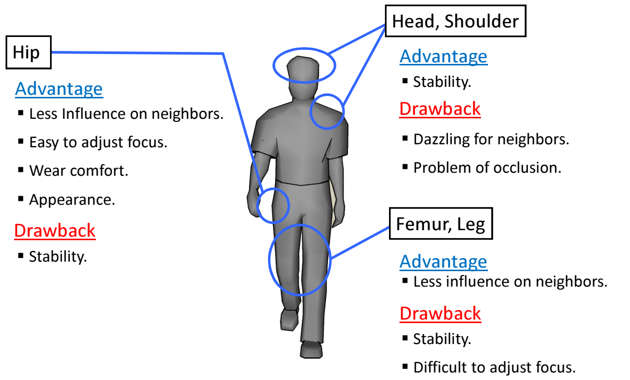


Figure 1: Selection of wearable part.

on the wall with a wrist worn projector. However, this is premised on use at state of rest. Although Konishi [14] and Yamamoto [32] projected information on the palm-top with a shoulder worn projector, these are not hands-free. Also, though Mistry [20] projected information on the wall or real objects with head-mounted or neck-strap-mounted projector, it is limited on use at state of rest. Thus, a study about information projection method which can be used while moving with hands-free has almost never been proposed.

Therefore, we propose to project information on floors from a hip-mounted mobile projector to allow for indicating the information considering embodiment with keeping hands-free while moving [31]. To realize projection in real environment, projection surface should be ensured with stability as well as possible even in environmental change. Most studies which deal with projection in real environment have focused on choosing a wall as a projection surface. However, it does not always exist near a user. Also, considering use of a projector which uses halogen lamp or LED as light source (except a laser projector), it is preferable not to so change a distance between a projection surface and a projector in terms of focal distance. For these reasons, in this study, floor is selected as a projection surface, with the emphasis on stable projection support. Besides, as a suitable wearable part, a hip is selected on the grounds that with or without necessity of adjustment of focal distance, influence on neighbors, feeling of wearing, and appearance [7] (Figure 1).

However, considering the use in motion, there are issues in terms of visibility. It is clear that following factors affect user viewability.

- Floor color, pattern, and geometry
- Image blurring and distortion

With respect to the former issue that floor color, pattern, and geometry make less visibility, variety of improvements with image processing techniques have been proposed. For example, Nayar [21] and Fujii [6] compensated for projection pattern in accordance with texture of surface, Raskar [25] proposed a projection method for a non-planar surface. However, since these methods did not assume the use in the situation where a projector moves constantly, little is known about accuracy in motion. On the other hand, to solve the latter issues of image blurring and distortion caused by movement of a projector, some improvements have also been proposed. For example, Sukthankar [29] compensated for image distortion by calculating the correspondences between the vertices of the projected image frame and the projection surface frame. For compensation, Beardsley [2] and Cao [4] used a camera and their handheld projector prototype, Raskar [26] used wireless tags embedded in the environment and in physical objects. However, these methods cannot be used in arbitrary environments, because it is premised on tracking special visual characteristics or markers on the projection surface, or using pre-embedded tags. Moreover, it is difficult to apply it in motion, because none of these methods assumed the use in the situation where a projector moves constantly.

Although the former issues can be solved to a certain degree by choosing a floor suitable for projection, solution to the latter issues in motion has not been proposed. Therefore in this paper, we propose a stabilization method which reduces image blurring and distortion while walking that the commonest moving state of human. While we limit to a hip in this paper, it should be noted that this study can be applied to cases of attaching a projector to other upper body parts.

## 2 Proposition of Stabilization Method

As a stabilization method, following 2 approaches may be considered.

- Controlling the movement of the projector itself by using shock absorbers or other mechanical means
- Compensating for projected image on the fixed position against a user due to negate the estimated spatial displacement of the projected image

The former method would effectively stabilize the image, however, there would be issues of bulkiness, high power consumption, and difficulty of real-time control. On the other hand, there are 2 methods for the latter approach: adjusting direction of projection light to adequate position using a micro-mirror and so on, or deforming image itself leveraging image processing techniques. In recent years, by the appearance of laser projectors, some methods which adjust position of projection light using a micro-mirror or a DC motor have been proposed [30] [10]. However, size of common projector which uses halogen lamp or LED as light source is not so small yet. Hence, considering use of such projector, these methods would have issue of bulkiness. Also, real-time control is difficult under a situation where a projector sways terribly. Therefore, we adopt the latter manageable method, compensating image itself leveraging image processing techniques.

To compensate for the projected image while the user is in motion, the spatial displacement of the projector must be estimated. Some methods to estimate position and posture of moving object have previously been proposed. In first in this section, an ideal stabilization method which uses spatial displacement of the projector is mentioned.

Main factor of making viewability worth is sway of the projected image in accordance with user's motion. In particular, it lays a burden on a user who wants to see the projected image continually. Also, in the case of having a glance at the image, it takes a user a long time to catch up to look it if it is not projected to the position he/she assumes. Therefore, we aim to continually project the image on the floor where is pitched at a fixed distance from user's eyes so that he/she could see it with stability. That means keeping the distance between user's eyes and the image in the world coordinate system, by means of transferring the image by corresponding pixels in the device coordinate system of the projector as shown in Figure 2. However, it is difficult to estimate position of user's eyes with only some devices attached to a hip. Thus, in this research, an image is projected to the position where is pitched at a fixed distance from a hip. It is based on the premise that difference between translational displacement of a hip and eyes can be disregarded except direction of movement. We assume that we could get equivalent efficacy even if keeping the distance not between eyes and an image but a hip and an image.

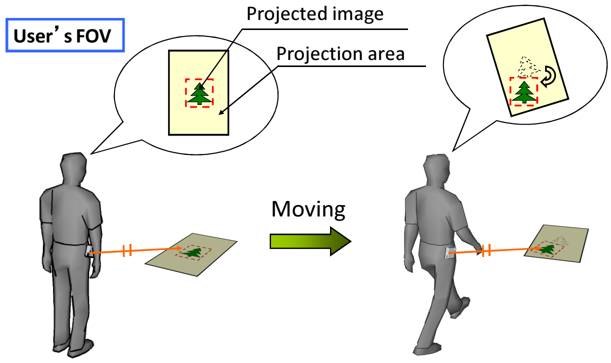


Figure 2: Concept of stabilization.

Process of stabilization is shown at Figure 3. In the figure, to simplify explanation, a matter is transferring 1 of 4 vertices of an image to some position in the device coordinate system. Firstly, as initial state, a left below vertex of the image is defined as

$$P_D = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{1}$$

when the image is centrally-arranged in the device coordinate system, then putting the projector at the origin of a world coordinate system (①), $P_D$ is converted to a world coordinate $P_{WS}$ under an angle of the projector (②). Next, detects the position and the posture of the projector at state of rest as calibration, then gets a homogeneous transformation matrix

$$R = \begin{bmatrix} C_yC_p & C_yS_pS_r - S_yC_r & C_yS_pC_r + S_yS_r & X \\ S_yC_p & S_yS_pS_r + C_yC_r & S_yS_pC_r - C_yS_r & Y \\ -S_p & C_pS_r & C_pC_r & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

(③). Here, $C$, $S$ mean cos and sin, index $y, p, r$ mean $Yaw, Pitch, Roll$ which is configured on the projector, $X, Y, Z$ mean world coordinate. Using the $R$ and the $P_{WS}$, position of a left below vertex $P_W$ is detected in the world coordinate system (④). Thus, a fixed distance $L$ between a hip and the image is detected (⑤). After this calibration, gets $R'$ similarly by estimating the position and the posture of the projector as needed (⑥), then detects $P'_W$, a target projection position by use of $L$ (⑦). Multiplying $P'_W$ by $R'^{-1}$, which is inverse matrix of $R'$, $P'_D$ is detected in the device coordinate system (⑧). Positions of other 3 vertices are detected by applying the same process. Above process enables to project the image on a target projection position where is pitched at a fixed distance from a hip continually, even while walking.

This stabilization method is predicated on estimating the position and the posture of the projector while walking. Recent investigations have demonstrated about some location-estimation methods. Vision-based methods, which use landmark or image feature in input image were proposed by Kato [12], Baratoff [1], Neumann [22], Oe [24], and Roggen [27]. Feiner [5], Hallaway [8], and Ni [23] used infrastructures such as GPS, infrared beacons,

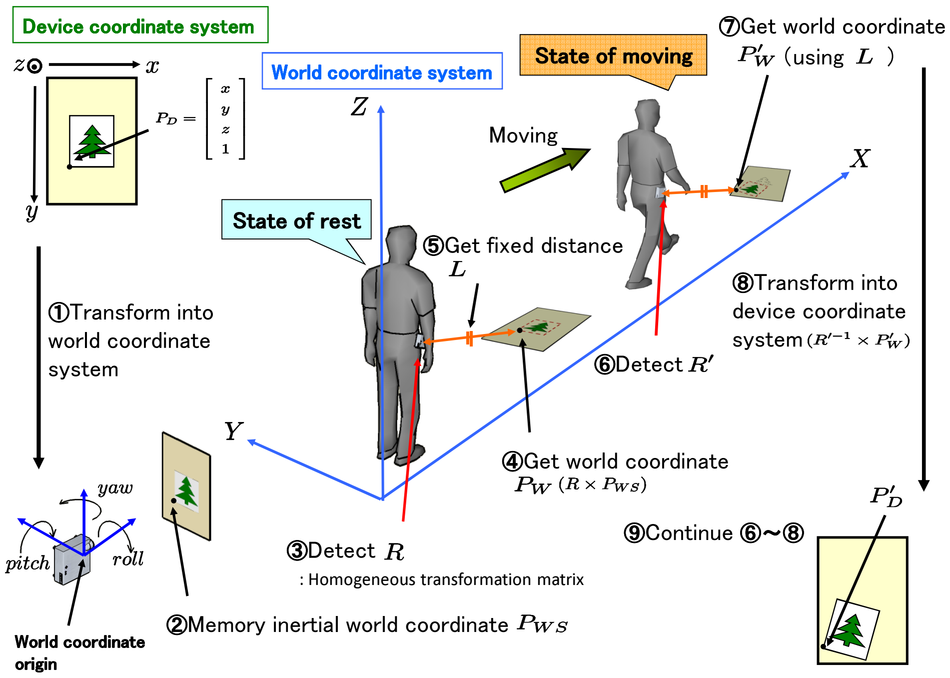


Figure 3: Idea of proposed stabilization.

RFID. Kourogi [15] estimated relative distance from a basing point by use of wearable inertial sensors. Moreover, Hamaguchi [9], Kourogi [16], and Satoh [28] combined these ways as hybrid method. Advantage of the first vision-based methods is low cumulative errors. However, it is difficult to use this method when a camera tracks an object which has few image features or judders itself. Advantage of the second methods which use infrastructures is high estimation accuracy under the equipped circumstances. However, installation costs and logistics involved in installing such infrastructures over large areas are serious issues. Then, the last methods, self-localization using wearable inertial sensors are attractive because it can be used anywhere without such expensive infrastructures. However, problem of this method is occurrence of cumulative estimation errors.

If we use vision-based method which uses image feature in the real environment, problems of hand-occlusion, motion blur, tracking speed, and tracking errors due to surrounding moving objects such as pedestrians or cars would make difficult real-time stabilization. Since the primary consider in this research should be real-time stabilization, we use inertial sensor-based method which has the advantage of processing speed. However, as stated above, inertial sensor-based method has a tendency to generate cumulative estimation errors. In particular, Tajimi [31] clarified the difficulty of estimating translational movement of the projector although rotational movement could be estimated with fairly accuracy by applying compensation. They conducted an experiment which compared the accuracy of inertial sensor-based method with vision-based method. Hence, we should propose an implementable inertial sensor-based stabilization method under such conditions. For this reason, firstly in this research, a dominant component of poor viewability is revealed. Then next, an original stabilization method is implemented by reference to the analysis.

## 3 INERTIAL SENSOR-BASED STABILIZATION

### 3.1 Analysis of a dominant component of viewability

In this study, to investigate how much rotational and translational movement affect the sway of the image respectively, we created a simulator which depicts movement of projected image observed by a user while walking (Figure 4). The simulator displays user's

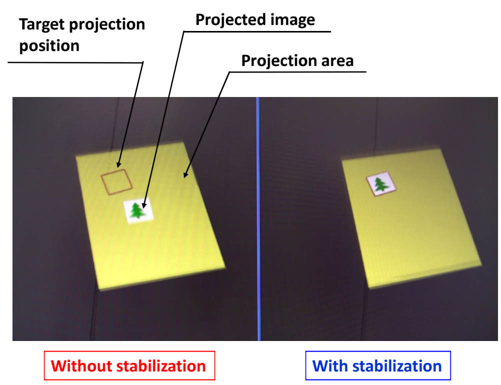


Figure 4: Screen of the simulator.

field of view, and can duplicate where the image is projected actually when a user looks continually at a target projection point pitched at a fixed relative position from him/her while walking. In this research, we executed simulation based on the positional data of a projector which was detected in Tajimi's experiment [31]. They measured the movement of a projector when a certain subject walked actually. In the simulation, to examine dominant moving components of viewability, the simulator computed and displayed position of projected image under the following conditions, then we compared each case how subjective viewability changes.

1. Both of rotational movement and translational movement can be detected ($Yaw, Pitch, Roll, Y, Z$ of the equation (2) are obtained)
2. Only rotational movement can be detected ($Yaw, Pitch, Roll$ are obtained, $Y, Z$ are fixed to initial values)
3. Only translational movement can be detected ($Y, Z$ are obtained, $Yaw, Pitch, Roll$ are fixed to initial values)
4. Neither rotational movement nor translational movement can be detected ($Yaw, Pitch, Roll, Y, Z$ are fixed to initial values - namely, without stabilization)

It should be noted that in this simulator, it is assumed that a user's head is fixed at a point certain distant from a hip.

After evaluating viewability of the image on the simulator by 1 subject, we found that the sway of the image in case 3. remains a major obstacle to viewability, which is about the same as case 4.. On the other hand, we got statement from him that the sway of the image in case 2. was reduced and it led to alleviate his feeling of discomfort. For this result, we could presume that applying stabilization under the condition where only translational movement can be detected has little effect on viewability, but only rotational movement can be detected has effect. For this reason, we can make an assumption that disregarding the translational movement does not so affect on accuracy of stabilization. Adopting this hypothesis, we implemented a stabilization method which considers only rotational movement estimated with a gyroscope - namely, $Yaw, Pitch, Roll$ of the equation (2) are estimated, then $Y, Z$ are fixed to constant values. Also $Y$ is initialized at regular time intervals to consider change of moving direction.

### 3.2 Configuration of experiment

To confirm the effect of our proposed method, we had fourteen subjects (gender: 1 female and 13 male; age: 21 to 27) walked straight along the corridor (floor color: white, illuminance: about 50〜100[lx], length: 18[m]) at natural walking speed, then answered the questionnaire which inquires viewability of the projected information. We prepared 3 images, figure, character, and map as projection information (Figure 5). Although it was depending on the height of hip of individual subject, each actual image size was about 85[cm]×85[cm], 30[cm]×30[cm] (per 1 character), and 115[cm]×115[cm] on the floor. Then we conducted experiment 3 sets (defined 1 image as 1 set) per 1 subject. A subject made 2

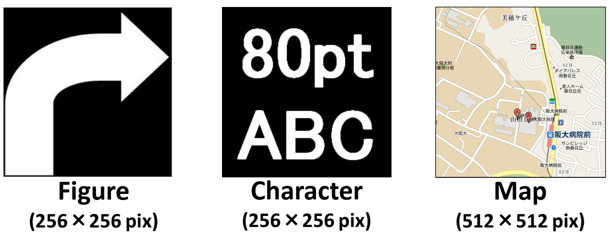


Figure 5: Projection information.

round trips with respect to each set. To negate order effect, we applied the stabilization in one of two round trips randomly; on the other hand, did not apply it in another trip. At this time, we explained to him/her that the first round trip was defined as A pattern; the second round trip was defined as B pattern. Also, in each round trip, he/she kept a close watch on the information in the first half trip. On the other hand in the next half trip, he/she changed his/her point of view between front face and the information accordingly.

It assumed the situation when a user has a glance at the information. He/She answered the following 3 questionnaires on a scale of 1 to 7 after each set:

Q1: Which did you easy to see the information comprehensively, A pattern or B pattern ?

Q2: When you kept a close watch on the information, which did you need less movement of point of view, A pattern or B pattern ?

Q3: When you had a glance at the information, which could you cognize it faster, A pattern or B pattern ?

Configuration of devices is shown in Figure 6. We used the LED light source mobile projector (Mitsubishi Inc.: LVP-PK20) and the 3-DOF Gyroscope (InterSense Inc.: InertiaCube3). As a computational resource, we used the common laptop computer (Apple Inc.: MacBook).

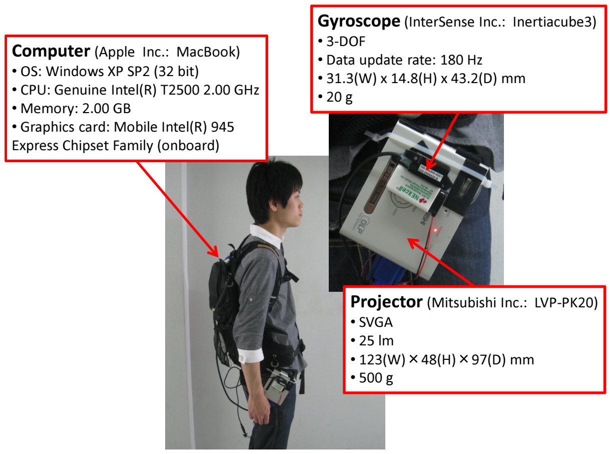


Figure 6: Configuration of devices.

### 3.3 Results of experiment

Results of experiment appear in Figure 7, Figure 8, and Figure 9. Although it differs in individuals, most subjects gave a high mark on the case with stabilization. In fact, there was statistically-significant difference in the 1 percent significance level (one-sample T-test, test value = 4) in each questionnaire, except the Q1 about map information.

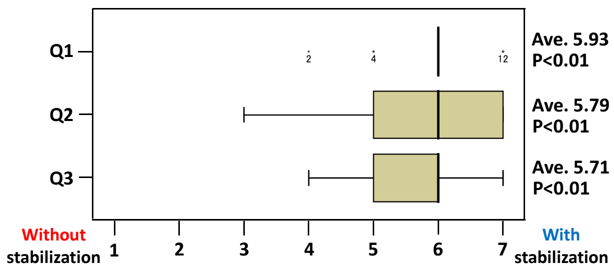


Figure 7: Projection information: Figure.

First, we describe our observations about each questionnaire. Significant difference are shown in the Q2 for each projection image. The result implies that a user who is keeping a close watch

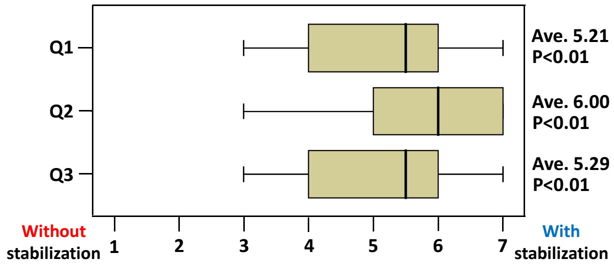


Figure 8: Projection information: Character.

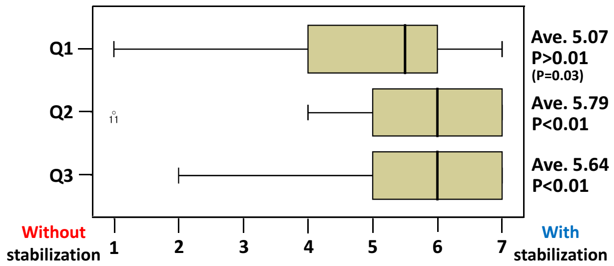


Figure 9: Projection information: Map.

on the information needs less movement of point of view when the stabilization is applied. It leads to reduction of user's burden to see information. Besides, the fact that significant differences are shown in the Q3 suggests that a user who have a glance at information can cognize it faster due to stabilization. It seems that the stabilization relieves a user of the bother of locating information on the floor. It can be continually projected on approximately the same relative position from him/her with stabilization. However, in the absence of stabilization, it cannot be projected on the position where user assumes when he/she has a glance at information. As to Q1, the result showed no significant difference only in the case of map information. We interviewed some subjects who gave a low mark actually, then determined the cause of poor viewability. It was frame out of the image from projection area. In this experiment, since the map information was the biggest image, it might too big to fit into projection area. Also, it is an interesting fact that one of these subjects is female, although there is no statistical worth because object person is only 1. Since the female's walk includes more rotational movement centering on her body than male, frame out could have occurred frequently. Therefore, in such case, we need to initialize *Yaw* more frequently. In addition, accurate drift compensation of a gyroscope is necessary.

Next, we compare the result with respect to each projection image. We found out cognition of information becomes more difficult as it becomes complex. The effect of the stabilization was seen strongly in the simplest projection image, the figure information, but we must state that stabilization is not perfect. In particular, character and number need more high-accuracy stabilization to be cognized because they are susceptible to the vibration. Also, restriction of size of projection image due to projection angle is issue to be resolved. In this experiment actually, frame out of the image made heavy influence on viewability. It is a problem that depending on a projector, nonetheless we should implement a method which enables projection on appropriate position in the future.

# 4 Discussions

## 4.1 Improvements

For the result of experiment in section 3, we could confirm the effect of our proposed stabilization method. However, as we stated there, it is indispensable to improve the method to make user easy to see more complex information such as characters or pictures. I would suggest that there are two main types of factors of poor viewability. One is micro vibration of the image, and the other is sliding of the image in long period of use. The former micro vibration is caused by micro fluctuation in estimation values of a gyroscope and time-delay in executing stabilization, except little influence of translational movement. The latter problem of sliding of the image is caused by drift-error of a gyroscope. In this paper, we classify these issues into as follows. Then we explore each improvement.

1. Fluctuation in estimation values of a gyroscope
2. Time-delay in executing stabilization
3. Drift-error of a gyroscope

### 4.1.1 Fluctuation in estimation values of a gyroscope

The fluctuation in values of a gyroscope, which occurs constantly, causes the micro vibration in the projected image. Thus, to suppress the fluctuation, we apply low-pass filter. The Figure 10 shows that the example of 10-point moving average filtering, removing components of higher frequency than 1.9[Hz]. Filtered data (red-line) has little fluctuation than raw data (blue-line). However, filtering compounds the time-delay problem. We mention about the issue in the next subsection.

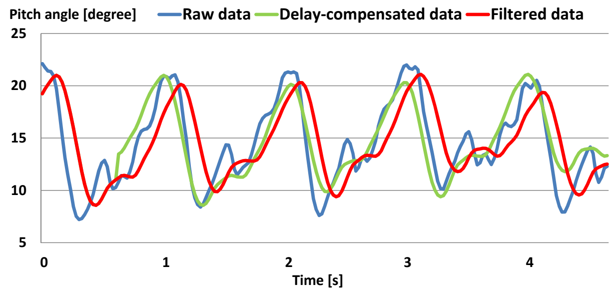


Figure 10: Low-pass filtering and time-delay compensation.

### 4.1.2 Time-delay in executing stabilization

To solve the problem of time-delay in executing stabilization, feed-forward control is required. Because cyclic pattern can be seen in rotational movement while walking, we can predict estimation values. A turn of the cycle is detected by calculating the correlation coefficient of previously obtained one period of template wave form and real-time values. Figure 10 shows the result of real-time compensation of time-delay. Delay-compensated data (green-line) is detected using data of the last cycle.

### 4.1.3 Drift-error of a gyroscope

The most serious problem of the inertial sensor-based estimation method in long period of use is cumulative errors. In this research, using the cyclic nature we stated in subsection 4.1.2, we will compensate for the drift-errors of a gyroscope. We note the average integral value of each cycle (Figure 11). As calibration, we detect reference average integral value of a template wave form, preliminary. Then, comparing it with that of real-time wave form, we realize the drift compensation. The results appear in Figure 11.

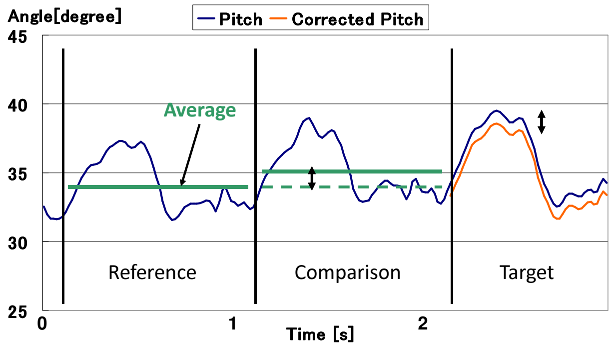


Figure 11: Idea of drift compensation.

### 4.2 Next steps

We might well have to consider the following factors:

- Applying to other moving state; other than walking
- Privacy
- Floor color, pattern, and geometry
- Brightness

As we used the stabilization method only while walking, we have not confirmed the effect under other moving state, yet. However, we suppose to apply it to other circumstances such as running. In this regard, however, a reference template wave of the rotational movement should be detected with respect to each circumstance.

Next, this system has a privacy issue. A user will want to deal with private information, which is why cell phones or PDA is mainly used as information browsing device. Ko [13] explored about issues of projecting information in the public space. In contrast, we can state that being able to share information and create the potential of interaction with others are that advantages of information indication with a projector. For example, McFarlane [19] states that information indication using a wearable projector can support interaction with others. At this research, we suppose to use this system for indicating task support information, which is less privacy, in the research facilities or warehouses. Interaction with others is a future research topic.

Also, there are issues of floor color, pattern, and geometry as already mentioned in section 1. We need a vision-hybrid system to solve these issues. Existing works [21] [6] [25], which compensate for projection pattern in accordance with texture of surface, or propose a projection method for a non-planar surface, are good references. In order to improve the accuracy of stabilization method, vision-hybrid will be study item.

Finally, brightness of a projector is also issue. If we use a wearable-sized projector, brightness is limited from about 10[lm] to 100[lm]. In considering the use in the daytime, a laser projector can solve those issues.

## 5 Conclusion

In this paper, we proposed to project information on the floor from a hip-mounted projector, in order to cover the shortcomings of existent mobile interface. Furthermore, we implemented and evaluated the stabilization method for the improvement of user viewability while walking. The result of our experiment clearly shows that the original stabilization which compensates for the position of the image can improve user viewability, although it remains the issues of accuracy. In addition, we made some suggestions for improvement so that we could make progress on the research.

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