Journal of Institute of Control, Robotics and Systems (2011) 17(9):892-896
http://dx.doi.org/10.5302/J.ICROS.2011.17.9.892 ISSN:1976-5622 eISSN:2233-4335

실외 주행환경을 고려한 카메라 기반의 RTGC 위치계측시스템 개발

Development of a Camera-based Position Measurement System for the RTGC with Environment Conditions

Hideki Kawai, 김 영 복*, 최 용 운
(Hideki Kawai[1], Young Bok Kim[1], and Yong Woon Choi[2])
[1]Pukyong National University
[2]Soka University

Abstract: This paper describes a camera-based position measurement system for automatic tracking control of a rubber Tired Gantry Crane (RTGC). An automatic tracking control of RTGC depends on the ability to measure its displacement and angle from a guide line that the RTGC has to follow. The measurement system proposed in this paper is composed of a camera and a PC that are mounted on the right upper between front and rear tires of the RTGC's side. The measurement accuracy of the system is affected by disturbances such as cracks and stains of the guide line, shadows, and halation from the light fluctuation. To overcome the disturbances, both side edges of the guide line are detected as two straight lines from an input image taken by the camera, and parameters of the straight lines are determined by using Hough transform. The displacement and angle of the RTGC from the guide line can be obtained from these parameters with the robustness against the disturbances. From the experiments with the disturbances, we found the accurate displacement and the angle from the guide line that have the standard deviations of 0.95 pixels and 0.22 degrees, respectively.

Keywords: rubber tired gantry crane, automatic control, image processing, line position measurement

I. INTRODUCTION

Container cranes are widely used to handle cargo in terminals and play an important role in efficient cargo shipping. Recently, improved cranes have been required for lower costs and improved shipping times, owing to the increased amount of cargo being handled. A RTGC (Rubber Tired Gantry Crane) is one of the improved cranes and is mainly used to handle cargo stacked in the terminals. For achieving more efficient handling, the automatic tracking control of the RTGC has been studied [1-3].

The automatic tracking control requires a relative position including a displacement from and an angle from an ideal path followed by the RTGC. To measure the relative position, traditional measurement systems have been developed by using a GPS [4], a camera, or a magnetic sensor [5]. A GPS based system uses multiple receivers of which two are placed onto the RTGC and one is located at a known location [4]. The position of the RTGC is measured with the acquired data from these receivers. This measuring principle allows the system to easily change the ideal path. However, the relative distance between two receivers on the RTGC may be changed due to the lower rigid structure of the RTGC, which may cause the decrease of the measurement accuracy. In contrast, the measurement system with a camera or a magnetic sensor directly measures the relative position of the RTGC from a guide line that represents the ideal path. The system with the magnetic sensor requires buried magnetic devices as the guide line. However, the buried magnetic devices tend to require a large amount of construction cost and have difficulty of changing the ideal path. On the other hand, the camera based system uses a painted guide line on the ground, which can easily be changed in relatively low cost. However, the measurement accuracy of the camera based system is affected by many disturbances such as cracks and stains of the guide line, shadows, and halation from the light fluctuation.

We propose a camera based measurement system that overcomes these disturbances. The proposed measurement system is composed of a camera and a PC that are mounted on the right upper between front and rear tires of a RTGC's side. In the measurment system, the both side edges of the guide line are extracted as two straight lines with edge detection. From these edges, prameters of the straight lines are calculated with Hough transform. Consequently, the relative position of the RTGC can be measured. From the experimental results conducted with the system, the robustness and the measurement accuracy of the system are verified.

II. SYSTEM DESCRIPTION

The automatic tracking control of RTGC requires measurement of its relative position including a displacement from and a angle to a guide line that represents an ideal path. The measurement system proposed in this paper measures the relative position by detecting the guide line from an input image. Fig. 1 schematically shows the measurement system. The system is composed of a

* 책임저자(Corresponding Author)
논문접수: 2011. 4. 18., 수정: 2011. 7. 6., 채택확정: 2011. 7. 20.
Hideki Kawai, 김영복: 부경대학교 공과대학 기계시스템공학과
(cai_electric@hotmail.com/kpjiwoo@pknu.ac.kr)
최용운: Soka University(choi@soka.ac.jp)
※ 본 연구는 2011년도 국토해양부 미래해양산업기술개발사업 지원에 의하여 연구되었음.
※ 본 논문은 2011 26회 ICROS 학술대회에서 초안이 발표되었음.

Copyright© ICROS 2011

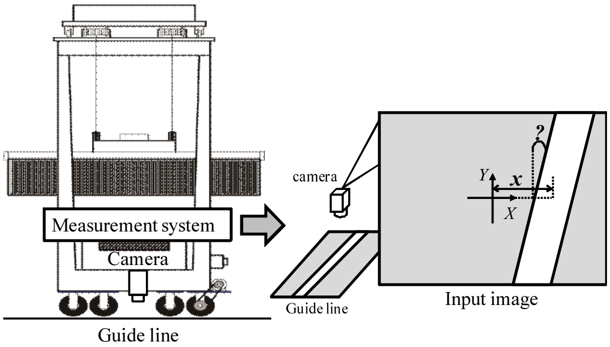


그림 1. 계측시스템 개략도.

Fig. 1. Schematic diagram of the measurement system.

camera and a PC that are mounted on the right upper between front and rear tires of a RTGC's side. When the RTGC moves correctly following the guide line, the guide line is captured at the center of an input image in parallel with Y axis. Therefore, the displacement is defined as the distance from the center of the line to the origin of the image on X axis, and the angle is also defined as the angle to Y axis.

III. POSITION MEASUREMENT WITH IMAGE PROCESSING

In the practical job site, the measurement accuracy of the system suffers from disturbances such as cracks, stains, shadow, and halation on the guide line as shown in Fig. 2. The crack and the stain on the guide line in Fig. 2(a) are made by RTGCs and trucks passing through. The shadow shown in Fig. 2(b) often arises from the relationship of RTGC and stacked cargo with light sources. The light sources also make halation in images (Fig. 2(c)). The robustness against these disturbances is required for the system in order to attain high measurement accuracy.

Fig. 3 shows the processing flow of the proposed measurement system. To overcome the robustness, the measurement system employs edge detection and Hough transform for position measurement. In the measurement system, edge detection is conducted in order to extract both side edges of the guide line after image acquisition. The extracted edges of the guide line can be regarded as two straight lines. Therefore, the parameters of the lines are calculated by Hough transform. With these calculated parameters, the relative position of the RTGC can be measured.

1. Edge detection

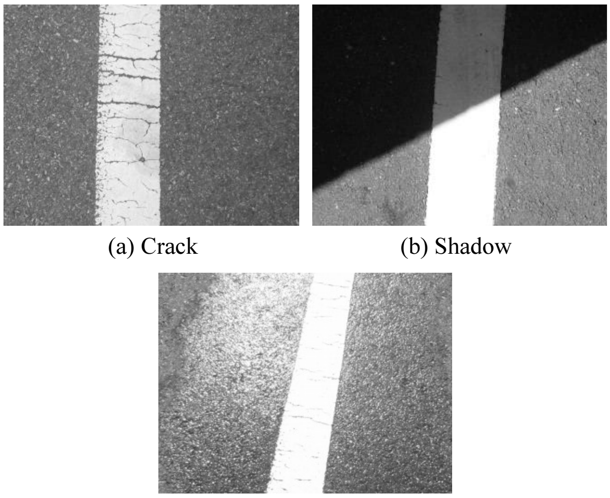
Generally, the edge detection extracts edges of objects as the intensity changes in an input image by using n×n convolution filters [4]. In the measurement system, 3×3 two sobel filters $S_x(i,j)$, $S_y(i,j)$, shown in (1) are used and convoluted with the input image.

$$S_x(i,j)=\begin{pmatrix}-1 & 0 & 1\\ -2 & 0 & 2\\ -1 & 0 & 1\end{pmatrix},\quad S_y(i,j)=\begin{pmatrix}-1 & -2 & -1\\ 0 & 0 & 0\\ 1 & 2 & 1\end{pmatrix} \qquad (1)$$

The convolutions of the input image, I, with the $S_x(i,j)$, $S_y(i,j)$ are shown as

$$D_{x,y}(x,y)=\sum_{j=0}^{2}\sum_{i=0}^{2} I(x-1+i, y-1+j)\times S_{x,y}(i,j) \qquad (2)$$

where, $D_x(x,y)$ and $D_y(x,y)$ are processed images that contain



(a) Crack (b) Shadow

(c) Halation (Reflection)

그림 2. 외란이 수반된 영상.

Fig. 2. Disturbances of input images.

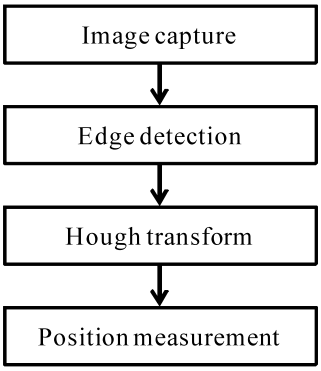
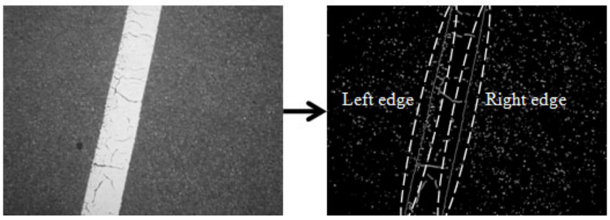


그림 3. 화상처리 순서도.

Fig. 3. Processing flow of the proposed system.



(a) Input image $I(x, y)$ (b) Edge image $E(x, y)$

그림 4. 소벨필터를 이용한 입력화상으로부터의 에지검출.

Fig. 4. Edge detection from an input image with Sobel filters.

intensity changes on the directions of X and Y axes, respectively. From these processed images, an edge image $E(x,y)$ is calculated with a threshold, t, as follows

$$E(x,y)=\begin{cases}1 & |D_x|+|D_y|\ge t\\ 0 & \text{otherwise}\end{cases} \qquad (3)$$

where, $E(x,y)$=1 means edges of objects in the input image. Fig. 4 shows the results of the edge detection. Fig. 4(b) shows an edge image $E(x,y)$ from an input image of Fig. 4(a). From Fig. 4(b), it is seen that the both side edges of the guide line are extracted.

The extracted edges can be regarded as two straight lines.

These two lines are useful to calculate the relative position of the RTGC. However, $E(x, y)$ also contains other edges on the cracks or the road that make it difficult to extract the lines. To accurately find the lines, Hough transform is used.

2. Hough transform

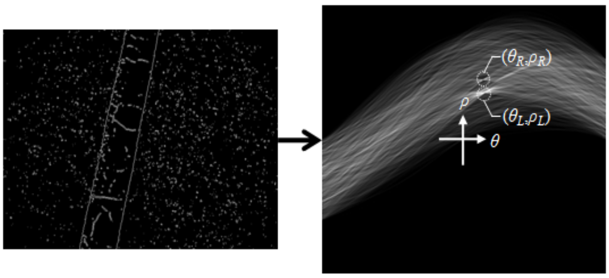
Hough transform is a method to detect straight lines from an edge image and represents the lines in ρ-θ plane with (4) [4].

$$\rho = x\cos\theta + y\sin\theta \tag{4}$$

In the Hough transform, each image coordinates (x,y) with $E(x,y)$=1 is transformed into a curve passing through the corresponding coordinates in ρ-θ plane. Consequently, the curves on a straight line in $E(x,y)$ intersect a Hough space coordinate (ρ,θ), which is the parameter of the straight line. Fig. 5 shows Hough transformation concerned with the edge image in Fig. 4(b). The right image of Fig. 5(b) represents the Hough image $H(\rho,\theta)$ from $E(x,y)$, where each pixel value represents the number of curves passing through the pixel. Therefore, the coordinates of pixels with local maximum values can be regarded as parameters of straight lines. In the measurement system, two coordinates with the top two local maximum values are detected as the parameters of the two straight lines of the guide line (ρ_L,θ_L), (ρ_R,θ_R), where $\rho_L<\rho_R$.

3. Position measurement

The relative position of the RTGC from the guide line is measured with parameters of two straight lines (ρ_L,θ_L), (ρ_R,θ_R). Fig. 6 shows the measurement principle. In the measurement principle,



(a) Edge image $E(x, y)$ (b) Hough image $H(\theta, \rho)$

그림 5. 에지화상의 Hough변환 결과.

Fig. 5. Hough transform concerned with an edge image.

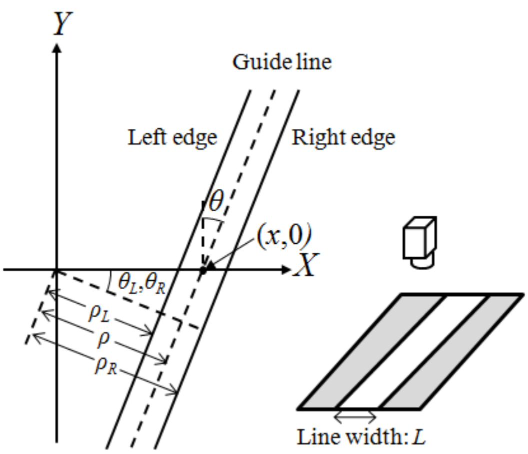


그림 6. 위치계측기법 개요.

Fig. 6. Scheme of position measurement.

we suppose an ideal line with the width of 1 pixel which lies midway between two lines. The parameters of the ideal guide line (ρ,θ) is calculated from (ρ_L,θ_L), (ρ_R,θ_R) with (5),

$$(\rho,\theta) = \left(\frac{\rho_L+\rho_R}{2}, \frac{\theta_L+\theta_R}{2}\right) \tag{5}$$

where, θ is the angle of the RTGC to the guide line. The displacement of the RTGC from the guide line in an input image, x, is defined on X axis and is calculated from (4),

$$x = \frac{\rho}{\cos\theta} \tag{6}$$

The actual displacement of the RTGC, D, is calculated with the ratio of the line width in the image to the actual one, L,

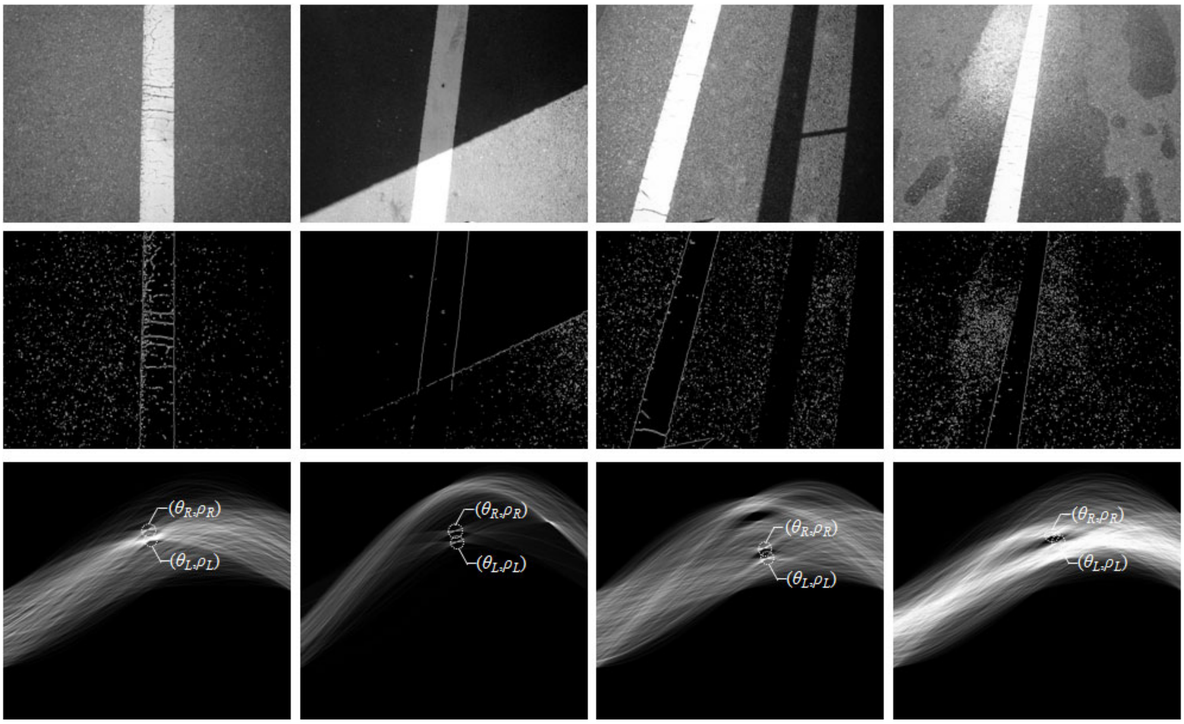
$$D = \frac{L}{|\rho_R - \rho_L|}x \tag{7}$$

IV. EXPERIMENT

We evaluated the measurement accuracy of the measurement system by using input images that contained a guide line with disturbances in outdoor environments. We used a hundred of input images that were taken with Panasonic Lumix DMC-FX520 and had the size of VGA (Width 640 × Height 480). Forty images contained cracks and stain, other forty images contained shadows on the line, and rest twenty images had halation on the line, respectively. From these images, the relative positions of RTGC were calculated with the system, which was composed of CPU: Core2^{TM} Duo 2.1 GHz, RAM: 2.0GB, and Matlab R2008b. In the system, edge detection, Hough transform, and detection of local maximum values were implemented with Matlab functions, referred to *edge*, *hough*, and *houghpeaks*, respectively [5]. In the experiment, the threshold t=0.1 was given to the function *edge*.

Fig. 7 shows the experimental results on the edge detection and Hough transform, where the Hough images contains detected coordinates (ρ_L,θ_L), (ρ_R,θ_R). Although edges of the cracks in Frame 1 were extracted in the edge image, two coordinates for the both side edges of the guide line were correctly detected. In Frame 53, since edges of the shadow were detected that passed over the guide line, three local minimum values seems to be contained in the Hough image. However, the number of edges of the line made by the shadow was smaller when it was compared with the number of the edges of the guide lines, so that the coordinates were properly found. In Frame 76, although shadows that are parallel to the guide line appeared, the correct coordinates were properly found, too. In Frame 97, the left side edges of the guide line could not be detected due to the effect of the halation. Nevertheless, the correct parameters were obtained from the Hough images.

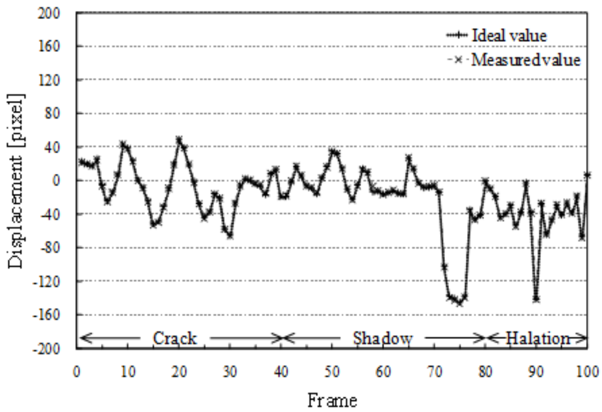
From the obtained parameters, we measured the displacements and angles with the system. For comparison, we manually calculated the displacements and angles as true values. Fig. 8 shows the measurement results. From the Fig. 8, the measurement succeeded in large range. In addition, Fig. 9 shows the measurement errors obtained from the comparison of measured values to true values. Unfortunately, the measurement errors of 6.46 pixels of x and 1.67 degrees of θ in Frame 58 are relatively bigger than other errors. However, because other measurement



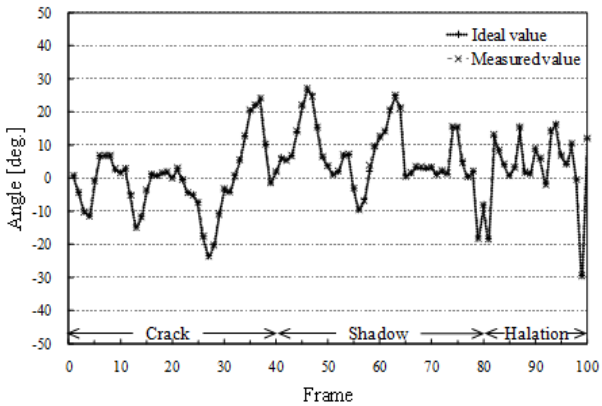
Frame 1 (Crack) Frame 53 (Shadow) Frame 76 (Shadow) Frame 97 (Halation)

그림 7. 촬영된 영상으로부터의 에지검출 및 Hough변환 실험결과.

Fig. 7. Experimental results on Edge detection and Hough transform.



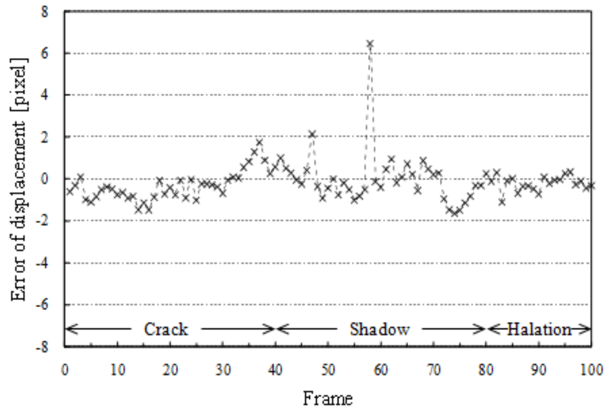
(a) Measured results of displacement x



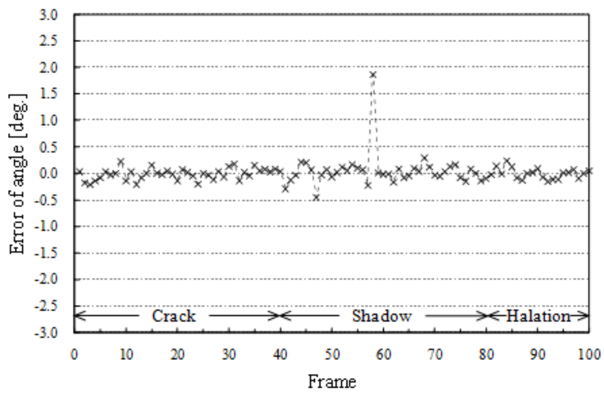
(a) Measured results of angle θ

그림 8. 실험을 통한 계측값 비교 결과.

Fig. 8. Experiment results with the ideal values for comparison.



(a) Measurement error of displacement x



(b) Measurement error of angle θ

그림 9. 실험을 통한 계측 오차 평가.

Fig. 9. Measurement error obtained from the comparison of measured values to ideal values.

errors are less than 2 pixels of x and 0.5 degrees of θ, the averages and standard variances are -0.17/0.95 pixels of x and 0.01/0.22 degrees of θ, which are enough small, respectively. In addition, abrupt errors like ones in Frame 58 may be eliminated by applying a linear filter like a Kalman Filter [8]. Therefore, we can expect that the measurement system has enough performance to satisfy the measurement accuracy required by the automatic tracking control of RTGC.

V. CONCLUSION

This paper described a camera-based position measurement system for the automatic tracking control of the RTGC, which measures the relative position from a guide line that RTGC follows. The measurement system is composed of a camera and a PC that are mounted on the right upper between front and rear tires of a RTGC's side. And it measures the relative position from an input image taken by the camera. To attain the robustness against disturbances such as craks, stains, shadow, and halation on the guide line in the image, the measurement system employs edge detection and Hough transform as image processing methods. In the edge detection, both side edges of the guide line are extracted by using two sobel fiters and are regarded as two straight lines. From the extracted edges, two prameters of the straight lines are calculated with Hough transform. Consequently, the relative position of the RTGC can be measured. The performance of the measurement system was evaluated by using input images containing a guide line in outdoor environments.

From the experimental results, the prameters of two straight lines were correctly detected from the line with the disturbances. From the detected parameters, the relative positions were measured with the -0.17/0.95 pixels of the erros of displacement on average and standard variance, and 0.01/0.22 degrees of the errors of the angle. From these results, we can expect that the measurement system has enough performance to satisfy the measurement accuracy required from the automatic tracking control of RTGC.

REFERENCES

[1] K. Obata, T. Sakamoto, N. Yoshioka, N. Fujisawa, H. Yoshikawa, and T. Monzen, "Grid-powered electric transfer crane," *Mitsubishi Heavy Industries Technical Review*, vol. 47, no. 2, pp. 15-18, 2010.

[2] B. Park, J. Park and Y. Choi, "Adaptive observer-based trajectory tracking control," *International Journal of Control, Automation, and System*, vol. 9, no. 3, pp. 534-541, 2011.

[3] S. Suh and Y. Kang, "A robust lane recognition technique for vision-based navigation," *International Journal of Control, Automation, and System*, vol. 9, no. 3, pp. 348-357, 2011.

[4] D. Kim and R. B. Langley, "On ultrahigh-precision GPS positioning and navigation," *Journal of the Institute of Navigation*, vol. 50, no. 2, pp. 103-116, 2003.

[5] K. Yasunaga, N. Watanabe, K. Tanouchi, M. Nishioka, and S. Nagashima, "Auto-steering system for transfer crane," *Mitsubishi Heavy Industries Technical Review* (in Japanese), vol. 37, no. 5, pp. 298-301, 2000.

[6] R. C. Gonzales and R. E. Woods, *Digital Image Processing*, 2nd Ed., Prentice Hall, 2001.

[7] R. C. Gonzales, R. E. Woods, and S. L. Eddins, *Digital Image Processing using MATLAB*, Prentice Hall, 2003.

[8] G. Welch and G. Bishop, "An introduction to the Kalman Filter," *Technical report TR95-041*, University of North Carolina at Chapel Hill, 1995.

Hideki Kawai

2004년 SOKA 대학 정보시스템공학과 졸업. 2006년 3월 동대학 대학원 정보시스템공학과 석사과정수료. 2010년 동 대학 대학원 박사과정 수료(공학박사). 2011년 5월부터 부경대학교 연구교수. 관심분야는 이미지프로세싱, 비전기반 센싱시스템 설계 및 응용.

김 영 복

1989년 2월 부경대학교 기관공학과 졸업. 1991년 2월 동 대학 대학원 기관학과 졸업(공학석사). 1996년 일본 KOBE 대학 대학원 박사과정수료(공학박사). 2001년 군산대학교 전임강사, 2002년부터 부경대학교 교수. 관심분야는 제어이론 및 응용, 특히 Dynamic Positioning System, 자동접안시스템구축을 비롯한 수상운동체 및 구조물의 운동해석 및 능동제어에 관심이 많음.

최 용 운

1990년 3월 일본 KOBE 대학 대학원 정보지능공학과 석사과정수료. 1990년 3월 동 대학 대학원 자연과학연구과 박사과정 수료(공학박사). 현재 일본 SOKA 대학 공학부 교수. 관심분야는 로봇비전 및 주행제어.