Engineering

Mechanical Engineering fields

Okayama University *Year* 1997

Obstacle avoidance by changing running path for an autonomous running vehicle applying visual servoing

Akira Gofuku
Okayama University

Yutaka Tanaka
Okayama University

Hiroyoshi Soda
Okayama University

Isaku Nagai
Okayama University

Obstacle Avoidance by Changing Running Path for an Autonomous Running Vehicle Applying Visual Servoing

Akio GOFUKU*, Yutaka TANAKA*, Hiroyoshi SODA**, and Isaku NAGAI*
* Department of Systems Engineering, Okayama University
3-1-1 Tsushima-Naka, Okayama 700, Japan
** Graduate School of Engineering, Okayama University
3-1-1 Tsushima-Naka, Okayama 700, Japan

ABSTRACT

This paper describes an improved running control algorithm based on the visual servoing in consideration of the turning back of a running path to avoid an obstacle on the path by changing the running path. This paper also describes an expeimental autonomous running vehicle to demonstrate the algorithm. As a vision sensor, the vehicle equips with a video-rate stereo range finder which processes color images from stereo CCD cameras and is developed in the authors' laboratory. From the several basic autonomous running experiments, it is concluded that the experimental vehicle runs smmothly any planned path composed of several teaching routes by transferring routes. It is also concluded that the vehicle can turn back on a path including turning back of route transference.

1 Introduction

Several types of techniques to control autonomous running vehicle are investigated [1]. These are categorized as model-based, behavior-based, and vision-based techniques. The model-based control technique is to control a vehicle by an environment map. However, it needs complete and accurate map and this is a serious problem for practical applications. The technique of behavior-based control such as sub-sumption architecture[2] has a difficulty to couple with controls in higher levels such as path planning. A typical technique of vision-based control is the look-and-move technique. However, this technique is affected from the measurement error of self position by inner measurements. Although the visual servoing[3] is categorized in the vision-based control technique, it does not suffer from this problem.

The basic idea of the vehicle running control by the visual servoing is that the movement of vehicle is controlled to match the image obtained by the vision sensors on the vehicle to a given image obtained beforehand on a teaching course. When the two images match each other, the given image is updated and the vehicle moves to the next position on the teaching route. From the running control mentioned above, the technique has several advantages. The movement control is not affected from the measurement error of self position by inner measurements. The technique does not need what is called environment maps although a series of images to guide a vehicle can be considered as a kind of environment map.

The previous study[4] proposes the usage of multiple routes to run from a start to a goal by moving a path combining several teaching routes and demonstrated the effectiveness through autonomous running experiments using an experimental vehicle. However, the vehicle can not avoid an obstacle on a planned path because the vehicle does not use explicit environment map to control its movement and previous running control algorithm does not consider turning back of the running path.

This study improves the running control algorithm to re-plan an alternative path to reach a goal, to turn back the running path to a suitable point to avoid an obstacle on the previously planned path, and to change to the alternative path.

The following of this paper describes the improved running control algorithm, the experimental vehicle equipped with a video-rate range finder[5] as a vision sensor, and two kinds of basic autonomous running experiments to avoid an obstacle on a running path..

2 Vehicle running control by visual servoing considering route transference

2.1 Vehicle control by visual servoing

The visual servoing is a robot control technique based on the characteristic features of a sensed image. There

0-8186-8025-3/97 $10.00 © 1997 IEEE

are two stages in the vehicle running control by the visual servoing, that is, (1) teaching stage and (2) controlling stage.

In the teaching stage, an operator moves a vehicle on a teaching route to be followed. During the movement, images are obtained by a vision sensor in an adequate distance or time interval. By analyzing the images, the values of parameters of characteristic points (landmarks) indicating route information are abstracted and are saved as a landmark map. Moreover, the knowledge related with the changes of the parameters of characteristic points is collected beforehand as a knowledge base. An example of this knowledge is "if a vehicle turns to the right, landmarks move to the left in the sensed image".

In the controlling stage, the vehicle runs autonomously using the landmark map and the knowledge stored in the knowledge base as shown in Fig. 1. At the position A in the figure, the sensed image of the landmark is smaller than the teaching image and its position is a little bit in the left side. This means that the location of the vehicle is right and far of the vehicle location when the teaching image was obtained. Then, the vehicle moves forward left. At position B, the sensed image of the landmark is still smaller than that of the teaching image. Therefore, the vehicle moves forward. If the sensed image matches to the teaching image, the teaching image is updated. Then, the vehicle moves to the location where the updated teaching image was obtained. In this way, the vehicle runs on a teaching route.

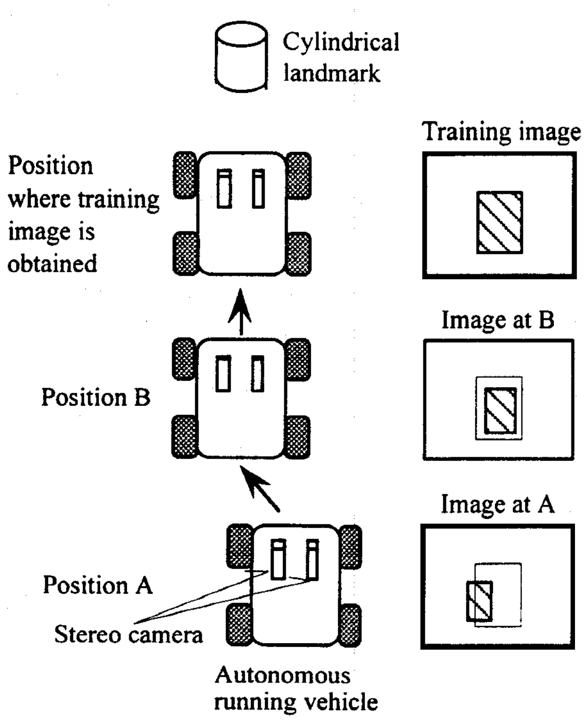


Fig 1. Vehicle running control by visual servoing.

2.2 Landmark map to run a path composed of multiple routes

This study utilizes a video-rate stereo range finder[5] as the vision sensor of an experimental autonomous running vehicle developed in our laboratory. The video-rate stereo range finder will be described in sub-section 3.2. The range finder detects the points of color change as characteristic points, measures the distances to the characteristic points from the parallax between the images from right and left cameras, and outputs them at the location of characteristic points in the left image as a monochrome image in which the brightness corresponds to the parallax. The parallax is in inverse proportion to the distance to a characteristic point.

Considering this vision system, the landmark information is composed of (a) color, (b) ratio of height to width, (c) x coordinate of the center of gravity in the distance image, and (d) parallax. The identification of a landmark is made by the color and the ratio of height to width. The x coordinate of the center of gravity of a landmark is related with the relative horizontal location between the vehicle and the landmark.

In order to consider route transference, the landmark map is composed of three kinds of frame data: (1) landmark list, (2) route list, and (3) route relation list. The route list is made by converting the information in the landmark list to be effectively used in a route transference. The route relation list is made by the crossing conditions of teaching routes.

Table 1 shows an example of landmark list. As shown in the table, the landmark list stores the information of landmarks which appear in an image. In the table, c, r, x, and d are color, ratio of height to width, x coordinate of the center of gravity, and parallax, respectively. The landmark list also stores the running direction to this image b. The running direction is used to reduce the size of landmark map[6]. Short bars in the table mean that the corresponding landmarks are not seen in the image or is not used in the autonomous running.

The route list is a list of landmarks seen in each route as shown in Table 2. The name of landmark L is added in the list in the order of appearance in the route. If several landmarks appeared firstly in a same image, the landmarks are added to the list in the order of evaluated value of landmarks E. In the present state, the evaluated value of landmark is the number of images that the landmark appears in a route.

The route relation list shown in Table 3 represents crossing route, image number on the original route just before crossing point, direction of route transference, and image number on the transferred route just before the corossing point. The route relation list is used to find posible transference teaching routes from a route and to

Table 1 Example of landmark list

Route k Image No.	Landmark 1	Landmark 2	----------	Landmark n
1	$c_{k11}, r_{k11}, x_{k11}, d_{k11}, b_{k11}$	$c_{k12}, r_{k12}, x_{k12}, d_{k12}, b_{k12}$	----------	—
2	$c_{k21}, r_{k21}, x_{k21}, d_{k21}, b_{k21}$	—	----------	$c_{k2n}, r_{k2n}, x_{k2n}, d_{k2n}, b_{k2n}$
⋮	⋮	⋮	⋱	⋮
m	—	$c_{km2}, r_{km2}, x_{km2}, d_{km2}, b_{km2}$	----------	$c_{kmn}, r_{kmn}, x_{kmn}, d_{kmn}, b_{kmn}$

Table 2 Example of route list

Route No.	Landmarks (Evaluated value)
1	L_{11} (E_{11}), L_{12} (E_{12}), ..., L_{1n_1} (E_{1n_1})
2	L_{21} (E_{21}), L_{22} (E_{22}), ..., L_{2n_2} (E_{2n_2})
⋮	⋮
l	L_{l1} (E_{l1}), L_{l2} (E_{l2}), ..., L_{ln_l} (E_{ln_l})

Table 3 Example of route relation list

Route No.	Route No. after transition	Image No. before transition	Direction of route transition	Image No. after transition
1	R_{11}	Im_{11}	*Left*	$Im_{R_{11}1}$
1	R_{12}	Im_{12}	*Right*	$Im_{R_{12}1}$
⋮	⋮	⋮	⋮	⋮
l	R_{lp}	Im_{l1}	*Left*	$Im_{R_{lp}1}$

decide route transference point.

2.3 Path planning

The running path composed of several teaching routes is planed beforehand from the images on the start and goal using the landmark map described in the previous sub-section. In the path planning algorithm, the start and goal are assumed to be the positions where teaching images are sampled.

The path planning algorithm is composed of (i) running path planning and (ii) route transference planning.

In the running path planning, a start and goal is assumed to be the location where teaching image is obtained. Firstly, the teaching route and image number of the route of the start and goal are firstly identified using the landmark list. If the route including the start is not the route including the goal, a route to follow after route transference is selected using the route relation list. If the route does not still reach the goal, another route to be transferred from the previous or current route is selected. This procedure is repeated until the route including the goal is selected. In the case that no more route is selected, it is concluded that no path exists to run from the start to the goal.

Because teaching routes are not so many in the experimental conditions which will be described in subsection 3.3, all possible paths from start to goal are planned. The reoute transference planning described in the following paragraph is also made for all route transference points.

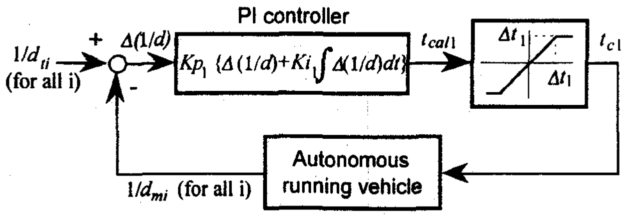
The route transference planning firstly selects two of the landmarks in the teaching image just before the cross section of the routes which are followed before and after route transference. The selection is made according to the evaluated value of a landmark. Then, the parallaxes to the landmarks to begin route transference are determined from the parallaxes in the teaching image and a predetermined allowance parallax value. Finally, the landmark which is not the selected landmarks and appears firstly after route transference is registered as a transference termination landmark.

2.4 Re-planning of running path

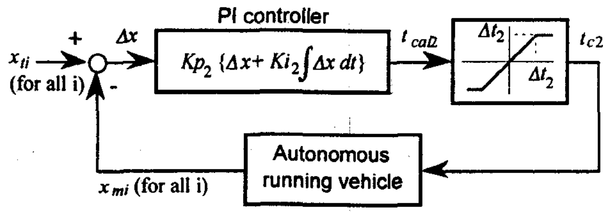
When an obstacle is found on a planned path, re-planning of running path is made. Firstly, the teaching route on which the vehicle is running is identified based on the planned path and the number of route transference slready made. Then, a new path is found to avoid the obstacle and to reach the goal by the identified teaching route and the all planned paths. The route transference point from the original path to the new path is also determined.

2.5 Running control including turning back a planned path

The control of vehicle running is described in the following. Firstly, the next teaching image after the image sampled at the start is set to be the first target image. A vehicle is controlled to run so that the sensed image may coincide with the target image by the PI controller shown in Fig. 2. The parameters in the controller are determined considering the behavior of the experimental vehicle which will be described in Sec. 3. When the vehicle reaches the position to begin route transference, route transference is carried out by the landmarks for route transference and route tranference termination landmark. When the route transference ends, the sensed image is analyzed and the information about landmarks is stored for the turning back of the route transference. A new target image is set to run on the teaching route after the



(a) Running forward or backward control



(b) Turning right or left control

Fig. 2 PI controller for autonomous running vehicle.

route transference. When the sensed image maches to the target image, the target image is updated. This procedure is repeated until the vehicle reaches the goal.

When the vehicle finds an obstacle on the running path, the vehicle is controlled by the following two kinds of turning back controls. The one is to turn back on the teaching route. This control is easily made by showing the teaching images in reverse order. The other is to turn back a route transference. When the vehicle reaches the route transference termination point, the turning back a route transference begins. The vehicle is controlled to run in the reverse direction of the route transference. The turning back ends when the vehicle reachs the route transference point.

3 Experimental Autonomous Running Vehicle

3.1 Configuration of vehicle

Figure 3 shows the experimental autonomous running vehicle system. By processing in real-time the images from right and left cameras, the video-rate stereo range finder[5] obtains a distance image of a scene where the distance information to objects is expressed as the brightness of image. The distance image is transmitted to the host personal computer through the UHF transmitter, receiver, and the monochrome image capture board. The movement control signals are generated in the host computer by the algorithm described in Sec. 2. Then, they are transmitted to the vehicle through the D/A converter and the radio control system.

3.2 Video-rate stereo range finder

The video-rate stereo range finder is a modified version from the one[5] to have the following feature (3). The range finder processes the color images from right and left CCD cameras and outputs distance images in video-rate. This subsection outlines the characteristic feature and the principle of the range finder.

The characteristic features of the range finder are in the following.

(1) The range finding is made by an electric circuit. By this feature, video-rate measurements of the distance to the objects in a scene are realized.

(2) The characteristic points in a scene is detected by the relative comparison of the color of objects. This

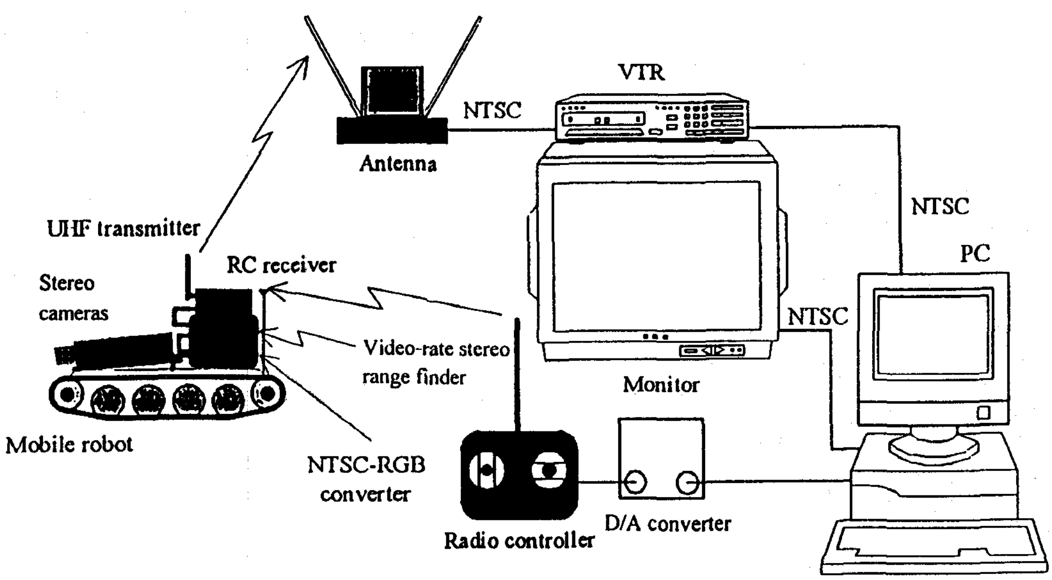


Fig 3. Configuration of experimental autonomous running vehicle system.

feature contributes to the high distance acquisition rate.

(3) By considering the interlace scanning of TV monitor, the distance image of the objects of a color is output in odd scanning lines and that of another color is output in even scanning lines so that a monochrome image capture board can treat two colors. This feature makes the vehicle to use many landmarks.

The RGB signals from binocular cameras are input to a range finding circuit. It detects color boundaries where the color changes in a scanning line of CCD camera and recognizes them as characteristic points as shown in Fig. 4. The range finding circuit also memorizes the color at a short time after the color change as the color of characteristic point. Based on the color, it searches corresponding characteristic points between the images from right hand side (RHS) and left hand side (LHS) cameras. If the same color at characteristic points is detected, the points in RHS and LHS images are recognized as corresponding characteristic points. Then, the range finding circuit measures the distance to the characteristic points from the difference of positions (parallax) in the images between RHS and LHS cameras.

Figure 5 shows the block diagram of the range finding circuit. The RGB-signals from the RHS camera are fed to a trigger circuit that starts the counting of the parallax by the system clock when at least one signal among RGB signals traverse the threshold level. At the same time,

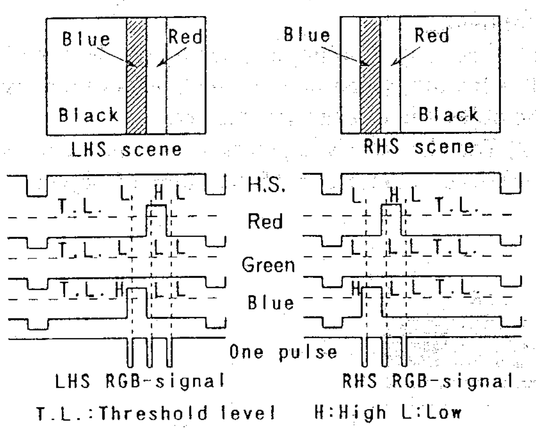


Fig 4. Detection of characteristic points.

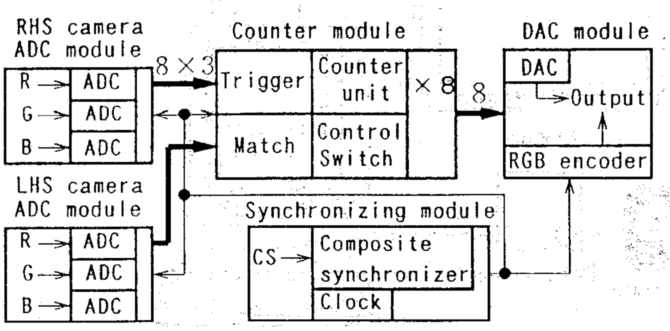


Fig 5. Block diagram of video-rate range finder.

the binary values representing the color at a short time after color change are memorized. The match circuit stops the counting only when the binary values of the RGB-signals after color change from the LHS camera coincide with those of the RHS camera within an allowance range. Then, the range finding circuit generates the parallax signal whose voltage is in inverse proportion to the distance to the color boundary.

3.3 Autonomous running experiments

Two kinds of basic autonomous running experiments are made. The one (experiment 1) is to run from a start to a goal through two planned paths. The other (experiment 2) is to turn back from a goal to a start. In the expeiments, six cylindrical landmarks are used. The color is red or blue and the height-diameter ratio is 1.0, 0.5, or 0.33.

Figure 6 and 7 show the vehicle traces in the

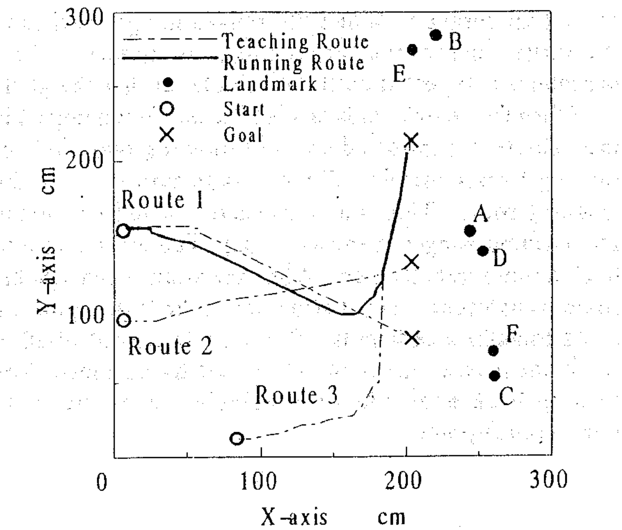


Fig. 6 Vehicle trace in an autonomous running.

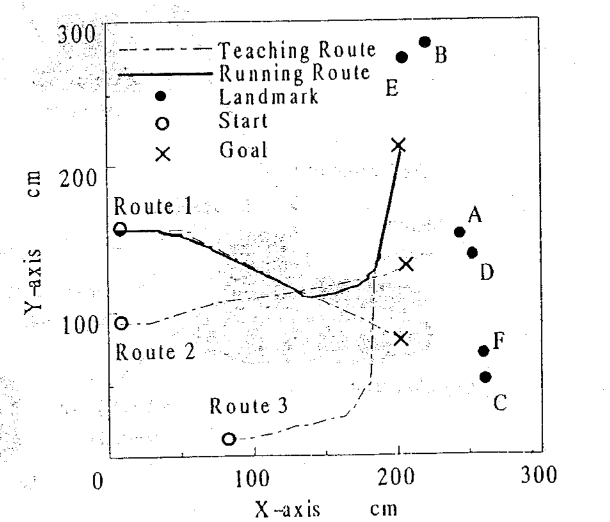


Fig. 7 Vehicle trace in an autonomous running.

autonomous running experiment 1. In the figure, "S" and "G" mean the start and goal of each route. In this experiment, the start and goal positions of running are the start of the route 1 and the goal of the route 3, respectively. The path planning algorithm plans the running path through the teaching routes 1 and 3 shown in Fig .6. The algorithm also plans the running path through the teaching routes 1, 2, and 3 shown in Fig. 7 as a alternative running path. From these figures, we can see that the developed vehicle runs correctly from the start on the teaching route 1 to the goal on the teaching route 3 by making suitable route transferences.

Figure 8 shows the vehicle trace in the autonomous running experiment 2. The start is the start of route 1 and the goal is the goal of route 2. The original running path is from the start to the goal through routes 1 and 2. In this experiment, it is assumed that no obstacle appear on the path of turning back. The vehicle turns back from the goal to the start by transferring the teaching route from route 2 to route 1. From the figure, it is confirmed that the experimental vehicle can turning back a path from the point where the vehicle finds an obstacle on the path to a suitable point to make a transference of teaching route or even to the start.

4 Conclusions

This paper describes an improved vehicle control algorithm by visual servoing in consideration of the turning back of a running path to avoid an obstacle on the path by changing the running path. This paper also describes an expeimental autonomous running vehicle which equips with a video-rate stereo range finder as a vision sensor. From the several basic autonomous running experiments, it is concluded that the experimental vehicle runs smmothly any planned path and turns back on a path including turning back of route transference.

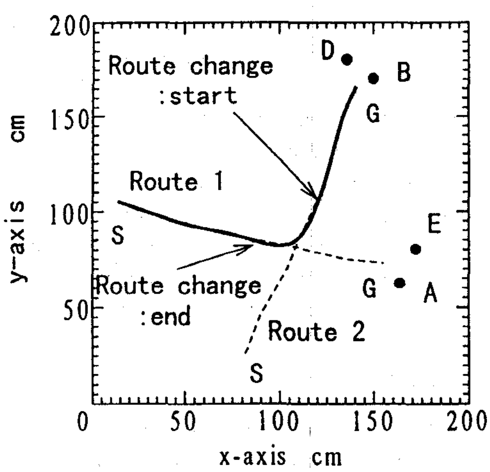


Fig. 8 Vehicle trace in an autonomous running.

A future problem is to consider the avoidance of an obstacle on a path by passing the side of the obstacle. This type of obstacle avoidance is accomplished by developing a technique to make an environment map near the obstacle based on the image information from the video-rate stero range finder and to plan a running course by combining the information of both the map and teaching images.

References

[1] Sato: "Generation and Understanding of Behaviors by Robots", *Journal of Robotics Society of Japan*, Vol.11, No. 8, 1993, pp. 1106-1110. (in Japanese)

[2] Brooks, R. A.: "A Robust Layered Control System for a Mobile Robot", *IEEE Journal of Robotics and Automation*, RA-2, 1986, pp. 14-23.

[3] Espiau, B., Chaumette, F. and Rives, P.: "A New Approach to Visual Servoing in Robotics", *IEEE Transactions on Robotics and Automation*, Vol. 8, No.3, 1992, pp. 313 - 326.

[4] Gofuku, A., Tanaka, Y, Matsuura, Y and Nagai, I, : "Development of an Autonomous Running Vehicle Applying Visual Servoing", *Proc. IASTED Int. Conf. on Mechatronics*, Hawaii, USA, August, 1996, 149-152.

[5] Tanaka, Y., Nakayama N. and Goto J.: "Development of High-Speed 3-D Range Finder Using Binocular Cameras", *Journal of Advanced Automation Technology*, Vol. 7, No. 1, 1995, pp. 66 - 72.

[6] Gofuku, A., Tanaka, Y., Hanada, Y., Matsuura, Y., Soda, H., and Kobayashi, M.: "Autonomous Running Technique by Visual Servoing Considering Route Transition and Running Behavior", *Transactions of the Japan Society of Mechanical Engineers*, to be published. (in Japanese)