Trajectory Control of a Mobile Robot by Gazing One Point

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Abstract

In recent years, making an autonomous robot is one of the most important and interesting research in the field of computer vision and robotics. An autonomous robot looks for his destination and moves as human beings do. Information on surrounding environment is very important for an autonomous robot. Vision plays very important role in obtaining information on the environment and gives a robot much information such as shape, color, etc. Our research aims at visual control for an autonomous robot to walk a corridor. In this paper we will propose a simple method to move a robot on a straight trajectory using the direction and the range of a gazing point which is not on the trajectory. We simulated and experimented with our two types of robot. Both types of robot have vision system which has two cameras. One robot can not change the relational position of two cameras, though the other robot can change. Experimental results shows that our method is effective in both types of robot.

1 Introduction

In recent years, making an autonomous robot is one of the most important and interesting research. An autonomous robot looks for his destination and moves as human beings do. Information on surrounding environment is very important for an autonomous robot. Vision plays very important role in obtaining information on environment and gives a robot much information such as shape, color, etc. Our research aims at visual control for an autonomous robot to walk a corridor.

Images from a camera are the projections of 3-D objects in a scene. We have to solve inverse problems to obtain 3-D information from images which are 2-D information. This problem is ill-posed and can not be solved generally because the images lost one dimensional information. We have to convert this problem form ill-posed to well-posed. Active Vision [1,2] has been proposed to solve this difficult problem. In Active Vision, the camera moves actively to get information on the environment, or often gazes a point in the environment. The point is also called as a fixation point. The ill-posed problem as described above will be a well-posed problem by gazing a point. There are many researches based on the paradigm of Active Vision. Our research is also gazing a point in the environment to control a trajectory of a robot. We can say that our approach is based on the paradigm of Active Vision.

There are many researches which are focusing visual control of a trajectory of robots. In [3], a robot moves to a target and aligns the camera orientation with the axis determined by the two locally parallel lines on the ground plane. Li et. al.[4] proposed a method to move a robot on a circle whose center is a fixation point. This research is based on the paradigm of Active Vision. The principal of both methods is very simple. We will propose a simple method to move a robot on a straight trajectory using the direction and the range of the gazing point which is not on the trajectory.

In this paper, we will describe a technique for identification of trajectory. Then we will propose controlling method of trajectory. Finally, we will show results of simulations and experimental results of our two robots.

2 Trajectory Identification and Control

In this section, we will describe characteristics of a trajectory of a robot. Using this characteristics, we will propose a new method to control the trajectory of the robot.

2.1 Modeling

Before describing characteristics of the trajectory of the robot, we make some assumptions. In this paper, we treat robots which has vision system. The vision system has two cameras. The robots can rotate their cameras toward an object in his environment. Using vision system, the robots can derive the direction of an object and the range information between the robot and the object.

We assume that the robot moves in a X-Y plane, which is parallel to the ground plane. This assumption shows that the robot does not have capability to move in vertical direction, and is reasonable for the robots which moves in a room.

When a robot wanders about a building, the robot has to move in a corridor. The corridor is usually narrow. The width of the corridor is often less than twice as much as the width of the robot. Zigzagging in the corridor is not good. It is important for the robot to go straightly. The problem, which we treat in this paper, is how to make a robot go straightly to a certain point gazing another reference point in the room environment.

As shown in Figure 1, let the camera coordinate, the robot coordinate and the world coordinate be $({}^CX, {}^CY, {}^CZ)$, $({}^RX, {}^RY, {}^RZ)$ and $({}^WX, {}^WY, {}^WZ)$, respectively. In the world coordinate, the ground plane is X-Y plane on which robot moves. The direction of X-axis of the world coordinate is the same as the trajectory of the robot which we want. The direction of X-axis of the robot coordinate is same as the direction of the robot. The Z-axis of the robot coordinate is parallel to the Z-axis of the world coordinate. In the camera coordinate, X-Y plane is parallel to the image plane, and Z-axis is same as the optical axis of the camera.

2.2 Trajectory Identification

Our objective is to make a trajectory of the robot be a straight line by looking at one point in the environment. We can find the following relation.

$$r = l \sin\theta \tag{1}$$

where

r : the distance between the gazing point and the trajectory

l : the distance between the robot and the gazing point.

θ : the angle between the trajectory and a line from the robot to the gazing point.

If the robot goes straightly, r becomes a constant value. Using this relationship, we can easily find whether the robot goes straightly or not.

2.3 Trajectory Control

Because of the existence of error, the robot can not go straightly without control. In this section, we will propose a method to control the trajectory of the robot.

Let's denote the value of r, l and θ at the start point of the robot as r_0, l_0 and θ_0, respectively. Observing r, we can judge whether the robot goes on a desirable trajectory or not. We need not change the direction of the robot while r is r_0. When r does not have the same value of r_0, the robot has to change its direction.

As described above, the X-axis of the world coordinate is the same as the trajectory of the robot. At the start point, the robot is on the origin of the world coordinate. The robot has two cameras. The positions of the two cameras are $(0, d/2)$ and $(0, -d/2)$ for the left camera and the right camera, respectively. (See Figure 2) The robot gazes a point $({}^WX_g, {}^WY_g, 0)$ in the world coordinate. α_r and α_l are the direction of the left camera and the right camera , respectively.

$$\begin{bmatrix} {}^RX_g \\ {}^RY_g \end{bmatrix} = \frac{d}{2\sin(\alpha_r - \alpha_l)} \begin{bmatrix} 2\cos\alpha_r \cos\alpha_l \\ \sin(\alpha_r + \alpha_l) \end{bmatrix} \tag{2}$$

d is the length of the base line of the two cameras. Using (2), we can derive l_0 and θ_0 which are l and θ at the start point, respectively.

$$\begin{aligned} l_0 &= \sqrt{{}^RX_g^2 + {}^RY_g^2} && (3) \\ \theta_0 &= \arctan({}^RY_g / {}^RX_g) && (4) \end{aligned}$$

The robot observes r while it moves. Comparing r with r_0, the robot detects error from the original trajectory. When the robot detects the error, the deviation from the trajectory in the robot coordinate is given as following,

$${}^RY = K\,{}^RX \tag{5}$$

where

$$K = \begin{cases} \frac{-{}^RX_g{}^RY_g + \sqrt{{}^RX_g^2\,{}^RY_g^2 - (r_0^2 - {}^RX_g^2)^2 (r_0^2 - {}^RY_g^2)^2}}{r_0^2 - {}^RX_g^2} & ({}^RY_g \leq 0\ ) \\ \frac{-{}^RX_g{}^RY_g - \sqrt{{}^RX_g^2\,{}^RY_g^2 - (r_0^2 - {}^RX_g^2)^2 (r_0^2 - {}^RY_g^2)^2}}{r_0^2 - {}^RX_g^2} & ({}^RY_g > 0\ ) \end{cases} \tag{6}$$

Also, the error of the direction of the robot is given by

$$\varphi = \arctan K \tag{7}$$

The robot changes its direction as much as φ to return the robot to the original trajectory. Performing this operation, the robot would keep the original trajectory.

3 Experiments

3.1 Experimental Systems

We experienced with two robots. The basic characteristics are same. The difference is their vision system. We will describe the details of each robots.

3.1.1 Robot "KOMA"

The first robot is named "KOMA". Figure 4(a) shows the photograph of KOMA. This robot can be divided into three units : Mobile Unit, Control Unit and Vision Unit.

Mobile Unit is a robot base which has two driving wheel. The robot base varies its direction by differential driving of the two wheel. This robot base can carry loads whose weight is less than 90 kg. Mobile Unit accepts commands from Control Unit via RS-232C port.

Control Unit has a 68040 based VME single board computer. This board computer has one Ethernet interface and four RS-232C interfaces. The board computer can communicate with other workstations via Ethernet using TCP/IP. According to commands from workstations, Control Unit sends commands to Mobile Unit and Vision Unit via RS-232C.

Vision Unit has two color TV cameras and their positioning system. Relative position of the two cameras is fixed. The positioning system has three degrees of freedom : pan, tilt and yaw. Control Unit can control position of cameras by sending commands to the positioning system. Hardware accuracy of the positioning system is 0.01 degree. The other parameters of the vision system are shown in Table 1.

3.1.2 Robot "KANI"

Figure 3(b) shows the photograph of the second our robot KANI. This robot can be also divided into three units : Mobile Unit, Control Unit and Vision Unit. Mobile Unit and Control Unit are same as the first robot.

Vision Unit consists of two color TV cameras and their positioning system. The two cameras can be positioned independently. Each positioning system has two degrees of freedom : pan and tilt. Control Unit can control position of cameras by sending commands to the positioning system. Hardware accuracy of the positioning system is 0.007087 degree. The other parameters of the vision system are shown in Table 1.

3.2 Simulation

Simulation has been studied. The origin of the world coordinate is the starting point of the robot. The robot gazes a point whose location is $(10r_0, r_0)$ in the world coordinate. The desirable trajectory is the X-axis of the world coordinate. We simulated two error condition.

The first case is as following. The error of the direction of the robot is constantly -5 degrees for every $r/2$ motion. In this case, the trajectory of the robot will be a circle without control. Figure 4(a) shows the effectiveness of our method. We can see that the trajectory of the robot is more desirable.

In the second case, the error of the direction of the robot is in the range between -5 degrees and $+5$ degrees with uniform randomness for every $r/2$ motion. The result is shown in Figure 4(b) and better than the former simulation. The robot keeps its position around the X-axis with control, while the robot goes to the gazing point without control.

3.3 Experimental Results

We experienced in a room using our two robots, KOMA and KANI. The gazing point is blue painted vertical region to make it easy to find in image processing. The distance between the gazing point and the X-axis is 60 cm. The distance from the start point of the robot and the goal is 600 cm. Both robots calculate φ at every 60 cm. The special calibration of the cameras did not performed. We used the center of the image plane as the origin of the X-Y plane of the camera coordinate.

Figure 5(a) shows the experimental result with KOMA. As described earlier, KOMA has two cameras whose relative position is fixed. We can not make both two cameras of KOMA gaze a same point on the center of camera at the same time.

KOMA obtains the coordinate of the gazing point $({}^{R}X_g, {}^{R}Y_g)$ using following relations instead of (2). The position of the gazing point is ${}^{Cl}X_g$ and ${}^{Cr}X_g$ in the left camera coordinate and the right camera coordinate, respectively.

$$\begin{bmatrix} {}^{R}X_g \\ {}^{R}Y_g \end{bmatrix} = \frac{d}{2({}^{Cl}X_g - {}^{Cr}X_g)} \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} 2f \\ {}^{Cl}X_g + {}^{Cr}X_g \end{bmatrix} \tag{8}$$

where f is the focal length of the camera lens and α is a direction from the trajectory to the optical axis.

The maximum error from the desired trajectory is 290*mm* in the positive region, 84*mm* in the negative region.

Figure 5(b) shows the experimental result with KANI. Each camera of KANI has two degrees of freedom, pan and tilt. In this case, we used equation (2). We can apply the result of section 2.3 directly. The maximum error from the desired trajectory is 14*mm* in the positive region, 63*mm* in the negative region.

4 Discussion

From the results of our simulation, the proposing control method is effective even if the robot goes on a circle without control.

From the result of our experiments, KOMA goes right in its nature. Applying our control, KOMA goes on around the desired trajectory. KANI also has the same characteristics of KOMA. The trajectory of KANI is corrected as in the case of KOMA. The reason why the both robots have such nature is unoptimized balance of weight. To get better characteristics of the robots, we have to refine the design of the robots.

Compareing the experimental the results of the two robots, the result of KANI is better than that of KOMA. The reason of this is mainly the difference of the accuracy of the vision system of each robots. The details are the followings,

1. The length of the base line of two cameras of KANI is longer than that of KOMA.
2. The focal length of the lens of KANI is longer than that of KOMA.
3. While KOMA uses the conventional stereo method to obtain the range information of gazing point, KANI actually gazes the gazing point with two cameras.
4. As described in section 3.3, calibrating the cameras of the robot did not performed.

We can increse the accuracy of visual information by the calibration of the vision system. The calibration is more effective for KOMA than for KANI. After the calibration, we will get similar results for both our robots.

5 Conclusion

In this paper, we proposed a new method to control a trajectory of a robbot. A robot has to gaze a point in a room when the robot uses our method. Our method only requrires the direction of the gazing point and the range information between the robot and the gazing point. Also we showed experimental results of our two robots, KOMA and KANI. Though we did not perform special calibration of cameras, experimantal results shows our mothod effective. In our experiment, the maximum error is 290*mm* for KOMA, 63*mm* for KANI. This error is enough small for a robot to walk in a coridoor.

References

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Table 1: Parameters of the Vision System

	KOMA	KANI
baseline of cameras	130 mm	600mm
focal length	16 mm	25mm
width of image	640 × 480	640 × 480
output signal	NTSC	NTSC

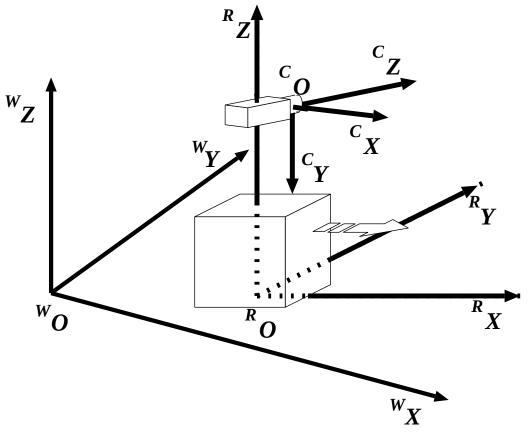


Figure 1: Relations between Coordinates

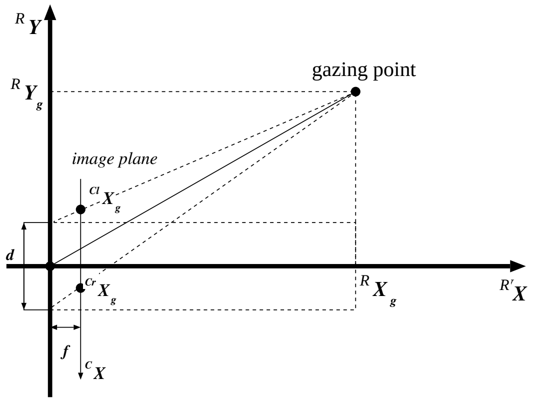
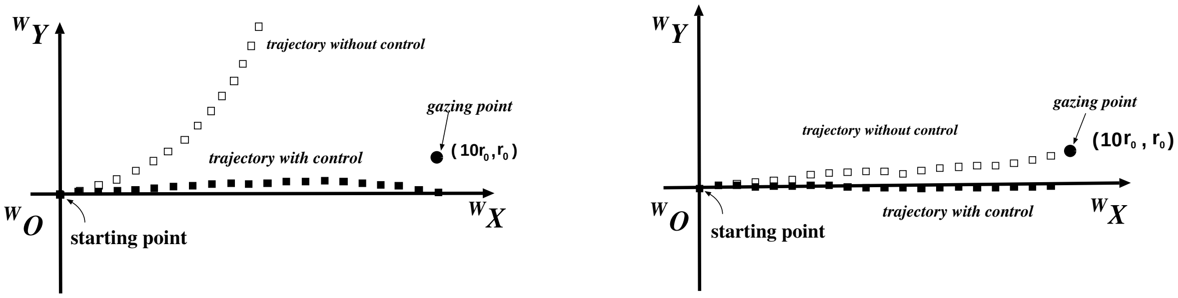


Figure 2: Relation of cameras and gazing point

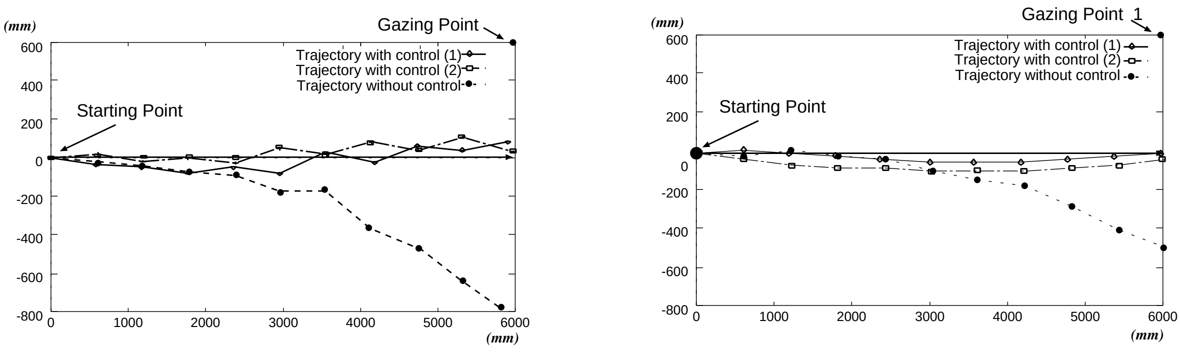
(a) Mobile Robot KOMA **(b)** Mobile Robot KANI

Figure 3: Photographs of robots used experiments



(a) Simulation 1 **(b)** Simulation 2

Figure 4: Results of Simulation



(a) Results by KOMA **(b)** Results by KANI

Figure 5: Results by Experiments