Proc. SPIE Advances in Intelligent Robotics Systems: Mobile Robots VI, Vol. 1613, Boston, MA, November 1991.

New vision-based approach for navigation

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1. ABSTRACT

Curved road tracking is one of the problems in active vision for Autonomous Vehicles. In search of a solution to this problem, we started with circular road following. In this paper we report on a new vision based method and its real time implementation for achieving the task of circular road following. Unique features of this method are : (1) it does not require the velocity information of the vehicle, and (2) it is very simple.

2. INTRODUCTION

In this paper we report on a new vision-based method and its real time implementation for achieving the task of circular road following. The method is based on four measurements: (1) the location of the tangent point on the road edge as projected on the moving camera image (i.e., the point on the road edge lying on an imaginary line tangent to the road edge and passing through the camera), (2) its optical flow, (3) the current steering angle, and (4) the amount of change in the steering angle. The advantages of this method are: (1) only a few measurements are needed for following the road, (2) the designed controller is independent of speed, and (3) the method is computationally inexpensive. The method was developed and implemented on a real system, at the Robot Systems Division at the National Institute of Standards and Technology (NIST).

Several different methods have been developed in the past. Dickmanns and Graefe [1] used monocular vision in their system. A window is opened for every important road feature in the image. Then, a single filter is utilized to track these features in a 4-D (space and time) world representation. The interpretation of the images is done in a 4-D world model instead of in the image coordinate system. The Martin-Marietta Group [2] has achieved results for selecting the road/non-road regions by using colored images. The Navlab, at Carnegie-Mellon University [3], used color images for detection of road/non-road regions. Once the road edges are detected, the vanishing point is used to generate steering commands. A range scanner is utilized for obstacle detection and terrain analysis. Work in road following has also been done at the University of Maryland [4] and at Ford Motor Company [5]. In most of the systems mentioned above, a 3-D representation of the world is recovered in order to generate steering commands. Dickmanns looks at the problem from the control point of view. Raviv and Herman [6] suggested simpler methods for road following. We combined one of these methods with control theory in order to generate steering commands.

Certain commercial equipment is identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the equipment identified is necessarily the best available for the purpose.

3. THE PROBLEM OF ROAD FOLLOWING

Figure 1.a shows a vehicle on a road. As indicated in Figure 1.b, let *h* be the instantaneous heading vector, *r* the radius of curvature of the road edge, and *s* the radial distance from the vehicle to the edge of the road.

We assume:

1. The vehicle is initially in a circular orbit (and at a distance *s* from the road edge),
2. The road is circular,
3. The heading of the vehicle in the image plane is known,
4. The radius of curvature of the vehicle's motion is measurable.

For conventional vehicles there is a one to one relationship between the radius of curvature of the vehicle's motion and the steering wheel angle. By using this relationship, the radius of curvature, denoted by *d*, can be measured from the steering wheel angle.

In general the problem of road following is to steer the heading vector *h* such that *s* will remain constant. In our case we propose a controller that will keep the vehicle in orbit given the previously stated assumptions.

4. SOLUTION TO THE PROBLEM

The visual feature used in this approach is the tangent point T (Figure 1.b) as projected in the image (i.e., the point on the road edge lying on an imaginary line tangent to the road edge and passing through the camera). Let the angle between this line and the vector *h* be θ. The value of θ can be obtained by extracting the position of the tangent point T from the image plane. From Figure 1.b;

$$s = d - r \tag{1}$$

$$r = d \cos\theta \tag{2}$$

by combining Equations (1) and (2);

$$s = d(1 - \cos\theta\ ) \tag{3}$$

Taking the derivative of Eq.3 with respect to time yields

$$s' = d'(1 - \cos\theta) + d \sin\theta\, \theta' \tag{4}$$

where $(\,')$ denotes the derivative with respect to time.

Note that the information which is necessary to compute s and s' is the location of the tangent point θ, its optical flow θ', the vehicle's radius of rotation *d*, and the change in this rotation d'. s and s' are used as input signals to the controller. Figure 2 shows the overall block diagram using these signals.

5. IMPLEMENTATION

The use of s and s' as feedback control signals was implemented at NIST using the Denning Mobile Robot. The system is composed of four components (Figure 3):(1) a CCD video camera, (2) PIPE real time image processor [7], (3) SUN work station, (4) Denning Mobile Robot [8]. The camera is mounted on top of the mobile robot. In our experiments, the robot's goal was to orbit a cylindrical object extending up from the ground. This made it easier to locate the tangent point in the image. Visual information is captured by the camera and sent to the PIPE. A few scanlines are transferred to the SUN where θ and θ' are extracted. For the Denning, the radius of rotation d, is given by

$$d = \frac{v}{\omega} \tag{5}$$

where v is the velocity of the vehicle, ω is its angular velocity. The change in the radius of rotation can be found by taking its first derivative:

$$d' = \frac{v'\omega - \omega' v}{\omega^2} \tag{6}$$

where v is the velocity of the vehicle, ω is its angular velocity. During the experiments, v was kept constant at 3cm/sec, therefore v' was zero. Substituting Equations (5) and (6) back into Equation (3) and (4) gives the following equations to be used as feedback signals.

$$s = \frac{v}{\omega}(1 - \cos\theta) \tag{7}$$

$$s' = -\frac{v}{\omega^2}\,\omega'(1 - \cos\theta) + \frac{v}{\omega}\sin\theta\,\theta' \tag{8}$$

Several controllers have been tried for closing the loop. We have achieved better results with the controllers which calculate the amount of change in the radius of rotation. Figure 4 depicts the controller that steered the heading vector for achieving the desired task. In Figure 4 $\varepsilon(t)$ and $\varepsilon(t-\Delta t)$ are the present and previous error signal, respectively. The error signal $\varepsilon(t)$ passes through a proportional and derivative (PD) controller and the result is subtracted from s'. The result is multiplied by a constant and subtracted from the current steering command ω_c to find the amount of change, $\Delta\omega$, in the steering angle. The controller coefficients are $K_1=-0.5$, $K_2=-0.2$, and $K_3=0.03$.

6. RESULTS and FUTURE WORK

Figure 5 shows a simulation result for a circular edge. The controller is capable of steering the vehicle into the desired orbit from an arbitrary location. In this simulation, the desired radial distance from the edge, s_d, is 30.5cm. The vehicle enters its desired path from an arbitrary initial point.

The results of our experiments on the Denning robot are very similar to the simulation results and may be seen on a video tape.

We are planning on extending this method for more general curved road following.

7. REFERENCES

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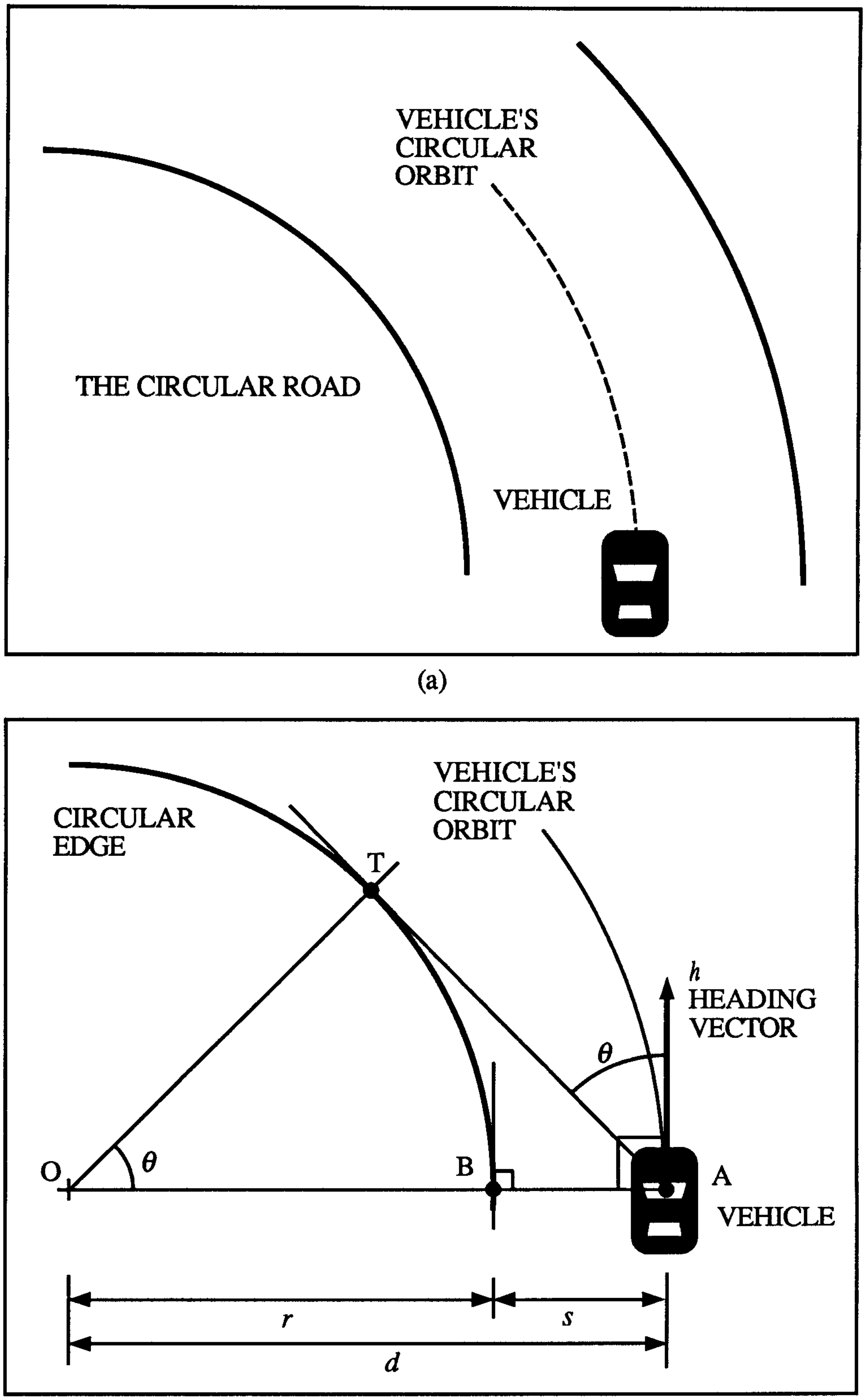
VEHICLE'S CIRCULAR ORBIT
THE CIRCULAR ROAD
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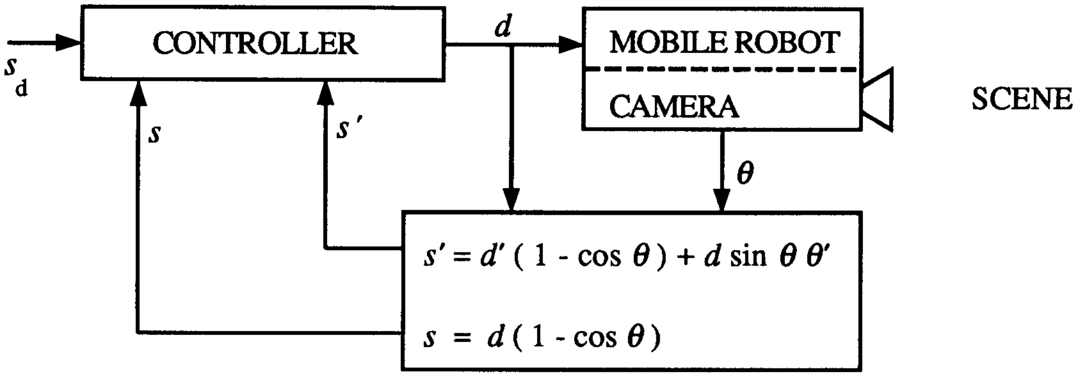
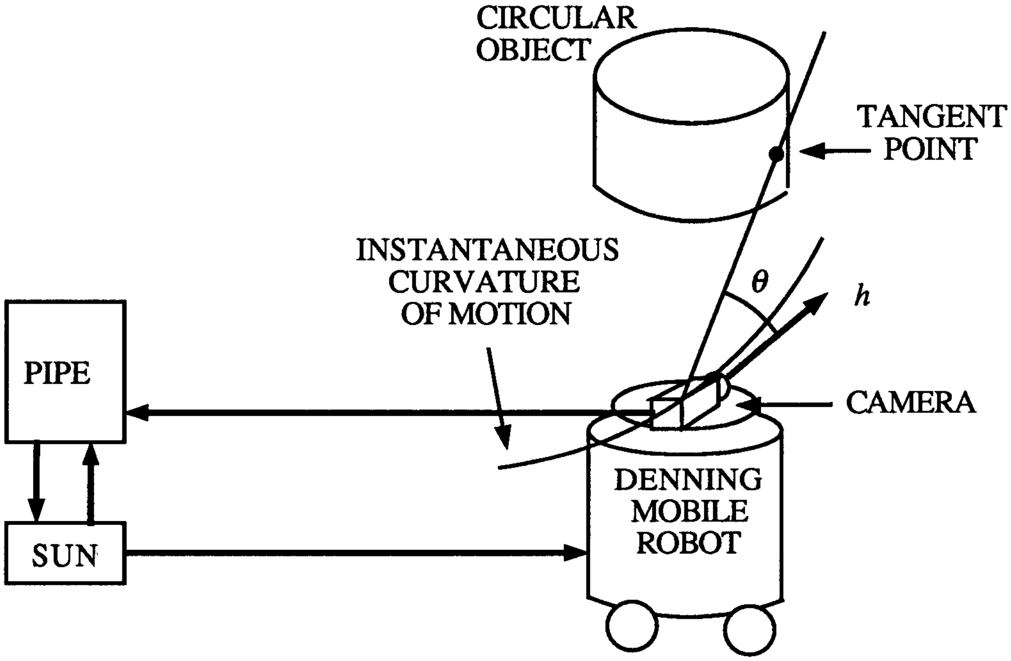
(b)

Fig.1 Circular edge tracking scenario.



CONTROLLER
s_d
d
MOBILE ROBOT
CAMERA
SCENE
s
s'
θ
$s' = d'(1 - \cos\theta) + d \sin\theta\,\theta'$
$s = d(1 - \cos\theta)$

Fig.2 Block diagram of the overall closed-loop system



CIRCULAR OBJECT
TANGENT POINT
INSTANTANEOUS CURVATURE OF MOTION
θ
h
CAMERA
PIPE
SUN
DENNING MOBILE ROBOT

Fig.3 System setup for orbiting around the circular object.

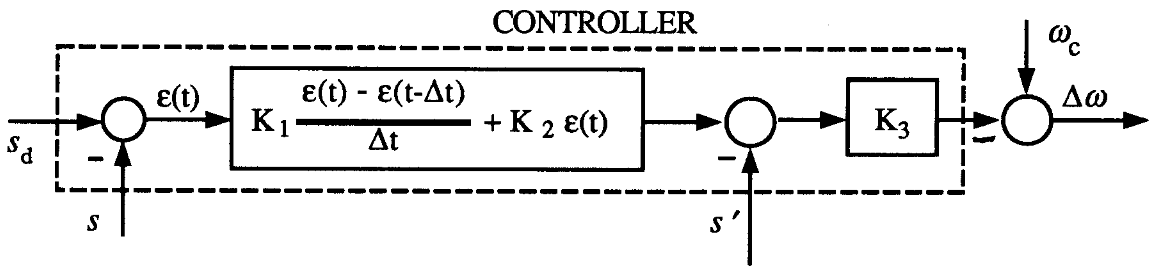

CONTROLLER
ω_c
$\Delta\omega$
$\varepsilon(t)$
$K_1 \frac{\varepsilon(t) - \varepsilon(t-\Delta t)}{\Delta t} + K_2\,\varepsilon(t)$
K_3
s_d
s
s'
−
−
−

Fig.4 The controller which was implemented on SUN.

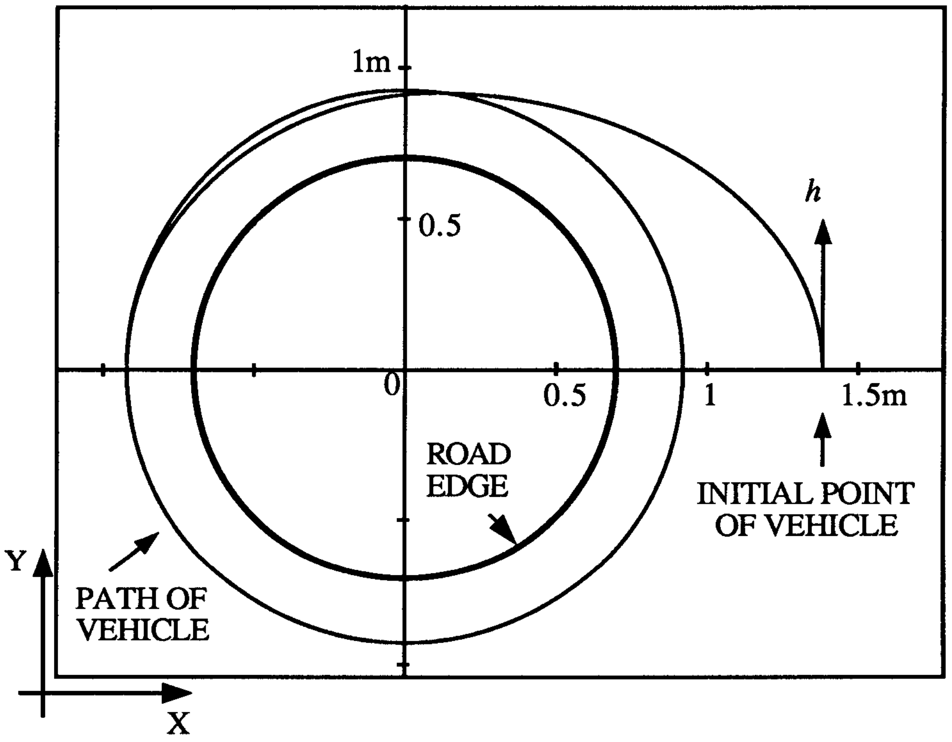


Fig.5 Simulation result for orbiting around a circular edge.