

ROAD FOLLOWING - A NEW APPROACH

by

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EXTENDED SUMMARY

1. General

In this summary 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 measuring 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), its optical flow, the current steering angle, and the 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, the Denning Mobile Robot [1], 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 [2] 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 [3] has

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achieved results for selecting the road/non-road regions by using colored images. The Navlab, at Carnegie-Mellon University [4], 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 [5] and at Ford Motor Company [6]. In most of the systems mentioned above, a 3-D or 4-D representation of the world is recovered. This is computationally expensive and noise sensitive.

Raviv and Herman [7] suggested simpler methods for road following using the tangent point and the Visual Field Theory.

2. The Problem of Road Following

Figure 1 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 is known,
- 4 . The radius of curvature of the vehicle's motion is measurable.

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.

3. Solution

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;

$$s = d - r \quad (1)$$

$$r = d \cos \theta \quad (2)$$

by combining Equations (1) and (2);

$$s = d (1 - \cos \theta) \quad (3)$$

Taking the derivative with respect to time of the last equation yields

$$s' = d' (1 - \cos \theta) + d \sin \theta \theta' \quad (4)$$

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' . We use s and s' as input signals to the controller. Figure 2 shows the overall control loop using these signals.

4. 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 [8], (3) SUN work station, (4) Denning Mobile Robot. The camera is mounted on top of the mobile robot. In our experiments, the robot's goal was to orbit a circular 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. s and s' are computed in this case by

$$d = \frac{v}{\omega} \quad (5)$$

$$d' = \frac{v'}{\omega} - \frac{v}{\omega^2} \omega' \quad (6)$$

where v is the velocity of the vehicle, ω is its angular velocity (which, for Denning, is equivalent to the steering command), and ω' is its angular acceleration. During the

experiments v was kept constant at 0.1ft/sec, therefore v' is zero. Substituting Equations (5) and (6) back into Equation (3) and (4) gives the following equations to be used as feedback signals.

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

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

We tried several controllers for closing the loop. Figure 4 depicts the controller that steered the heading vector for achieving the desired task. The error signal $\epsilon(t)$ 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 amount of change $\Delta\omega$ in the steering angle. The controller coefficients are $K_1=-0.5$, $K_2=-0.2$, and $K_3=0.03$.

5. Results

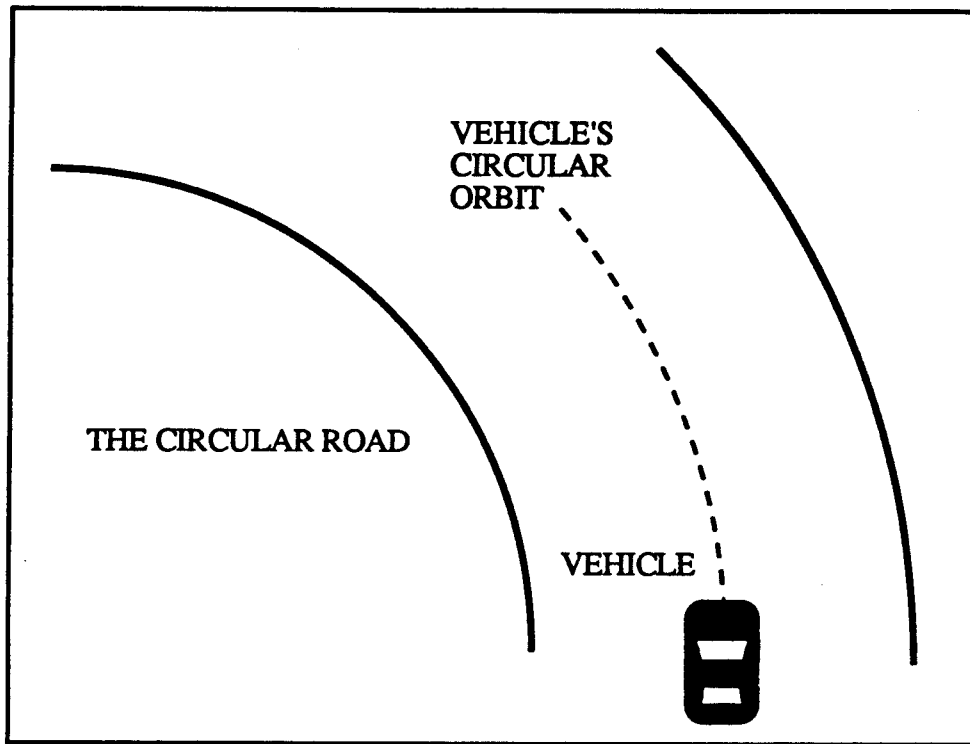
Figure 5 shows a simulation result for a circular edge. The controller is capable of steering the vehicle into the desired orbit from an arbitrary location. In this simulation, the desired radial distance from the edge, s_d , is 0.3m. The vehicle enters its desired path from an arbitrary initial point.

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

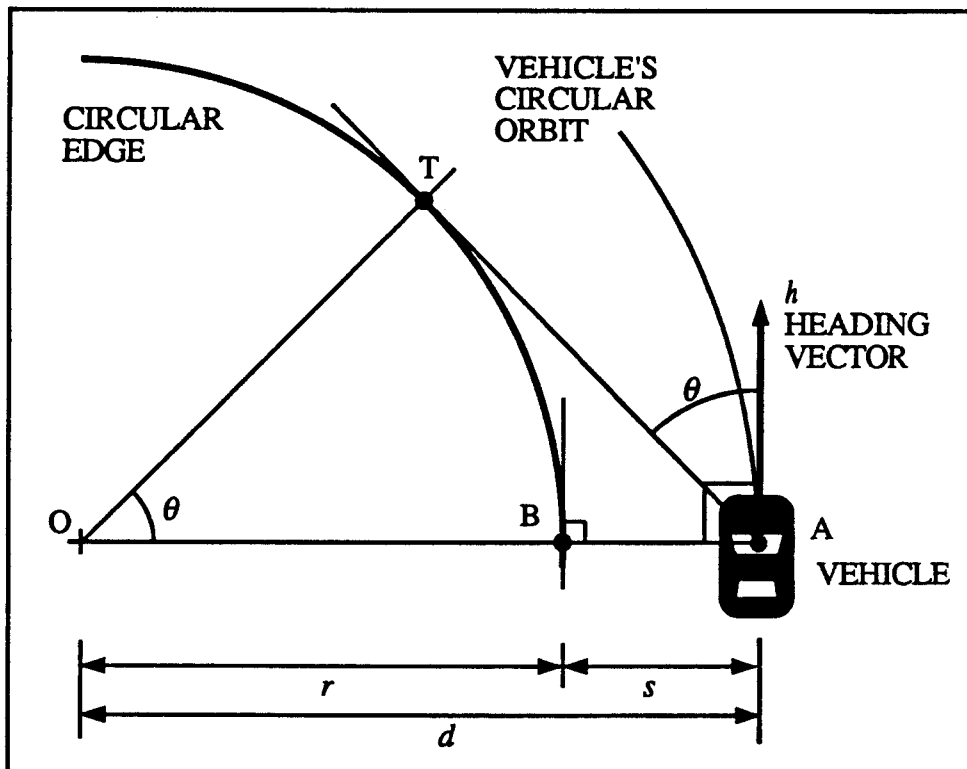
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(a)



(b)

Fig.1 Circular edge tracking scenario.

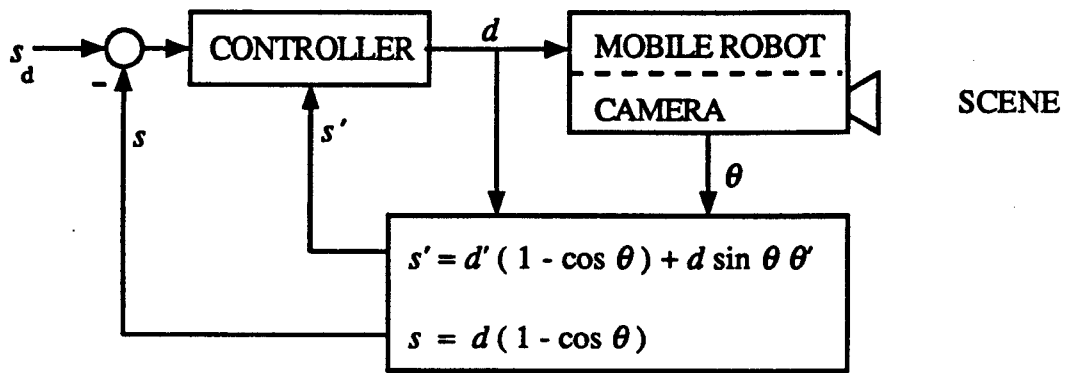


Fig.2 Block diagram of the overall closed-loop system

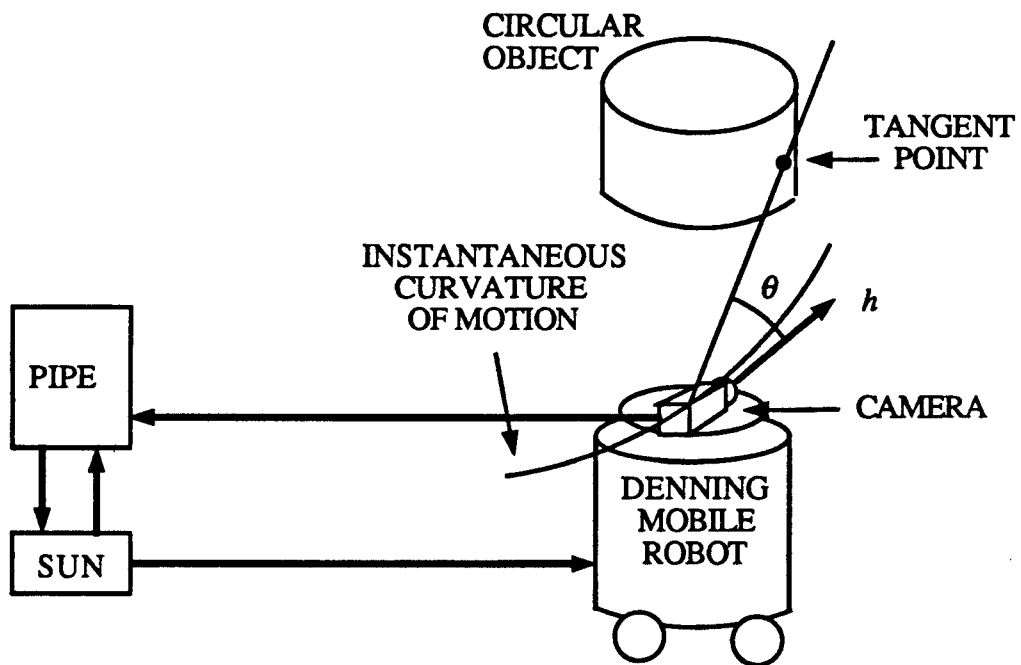


Fig.3 System setup for orbiting around the circular object.

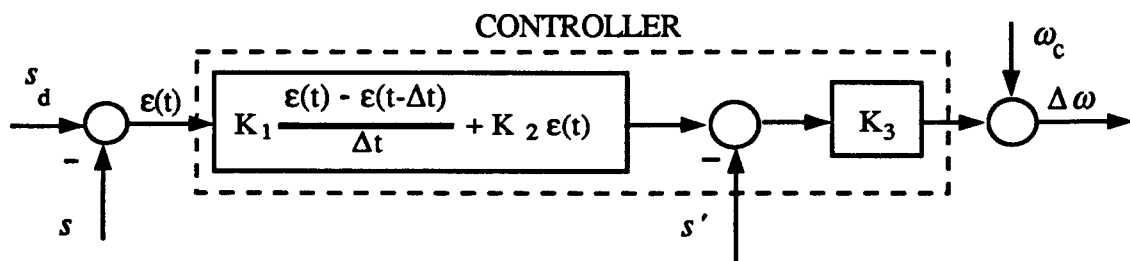


Fig.4 The controller that is implemented on SUN.

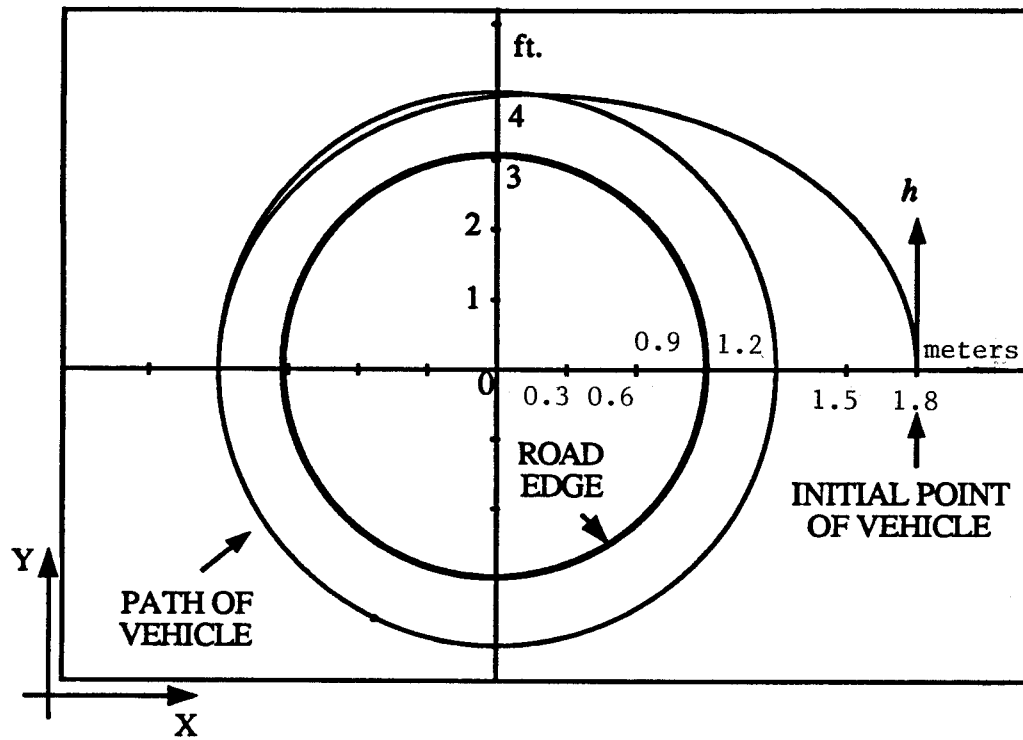


Fig.5 Simulation result for orbiting around a circular edge.