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LIGHT FOLLOWING VEHICLE CONTROL SYSTEM

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ABSTRACT

Sensory based control, particulary vision based control has become quite important in autonomous vehicle applications. For certain simple control tasks, as for example light source position detection and tracking, vision based control using video cameras is rather complicated. The paper describes simple vision sensor called "fuzzy eye" which is quite appropriate for such control tasks. The fuzzy eye principles, the control algorithm and the experimental setup are described as well.

Key words: vision based control, fuzzy control, light following, fuzzy eye, vehicle control

1. INTRODUCTION

In autonomous vehicle applications, sensory based control belongs to important control tasks. One of them is detection and tracking of the light source, either to find an object which produces the light, or simply to find a power source for charging vehicle batteries using photo voltaic cells.

A lot of research of light detection and light tracking was done, either at the University level (Morton and Hodge, 1996) or at the commercial levels (Novasoft, 1997). Most solutions are based on photoresistor light detectors mounted on servo sensor head which rotate and scann the vehicle sourradings "looking" for the light source.

In research described in this paper the nonrotating sensor head, called "fuzzy eye" (Stipaničev, 1992a, Stipaničev, 1992b, Stipaničev, 1993a) is described. The inspiration for the "fuzzy eye" came from the Animal Kingdom, more preciously from the Insect Kingdom. The fuzzy eye is a simple copy of the apposition compound eye of insect, and it is quite suitable for control tasks described previously: light source detection and tracking.

In our previous research with fuzzy eye we have developed different vision based servo control systems whose tasks were:

a) to point with the pointing device toward the light source positioned on a semicircle around the fuzzy eye and the pointing device (Stipaničev and Cecić, 1992), or
b) to position the "fuzzy eye" itself into direction of the light source (Stipaničev, 1993b).

The research described in this paper is further development of the "fuzzy eye" based control. The experimental vehicle was constructed and equiped with fuzzy eye. Its main control task was to detect the light source in its surroundings and to follow it.

Before describing the experiments in details a short description of the "fuzzy eye" will be given.

2. "FUZZY EYE" - ARTIFICIAL COMPOUND EYE

The "fuzzy eye" was concived as a man made copy of the apposition compound eye of insects (Fig.1).

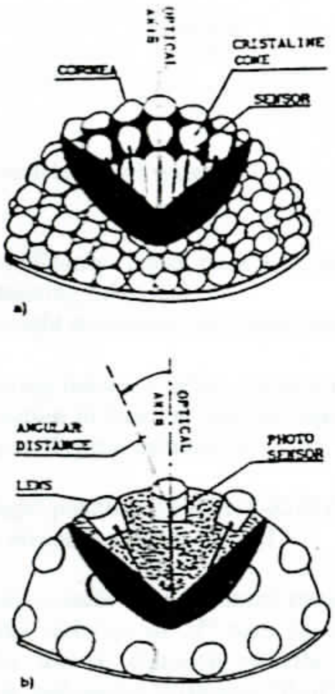


Fig.1. Cross section of the insect compound eye.(a) and the fuzzy eye (b).

It was constructed as an array of the light sensitive elements (photo detectors) arranged on a way that each of them "covers" one part of the space around the eye. Each photo detector had the narrow sensitivity curve which decreased with the angular distance from the sensor optical axis, as Fig.2 shows, so it was quite selective.

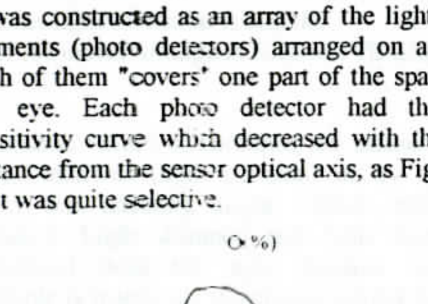
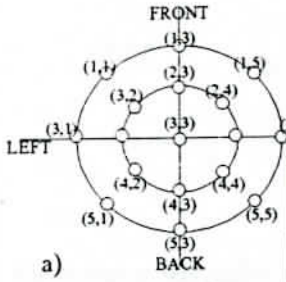


Fig. 2. Sensitivity curve of each photo sensor

When the light source was positioned in the part of the space covered by the certain photo detector, its signal was the biggest, but the other photo detectors were excited, too. As a consequence, signals received from the whole array carryed information of the light source position.

Our experimental "fuzy eye" was composed of 17 photo diodes. the signal produced by them could be represented by 5x5 matrix as Fig.3 shows. Number (x,y) corespond to the (row, column) position of the appropriate photo diode signal in vision signal matrix.



b)

$$\begin{bmatrix} (1,1) & \varnothing & (1,3) & \varnothing & (1,5) \\ \varnothing & (2,2) & (2,3) & (2,4) & \varnothing \\ (3,1) & (3,2) & (3,3) & (3,4) & (3,5) \\ \varnothing & (4,2) & (4,3) & (4,4) & \varnothing \\ (5,1) & \varnothing & (5,3) & \varnothing & (5,5) \end{bmatrix}$$

Fig.3. Sensors position in fuzzy eye (a) and appropriate vision signal matrix (b).

As some diodes were missing, for example diode (1,2) there are zeros in vision matrix on their places.

Vision signal was processed in fuzzy eye processing unit, dividing all values with the biggest one. On such a way its output matrix of relative values could be treated as fuzzy matrix called "Light Position According to the Fuzzy Eye". Typical example obtained from our fuzzy eye for light position "FRONT-RIGHT" is:

$$\begin{bmatrix} 0.07 & 0 & 0.21 & 0 & 1 \\ 0 & 0.23 & 0.025 & 0.12 & 0 \\ 0.07 & 0.12 & 0.17 & 0.12 & 0.27 \\ 0 & 0.12 & 0.11 & 0.13 & 0 \\ 0.07 & 0 & 0.13 & 0 & 0.15 \end{bmatrix} \qquad (1)$$

This matrix, and the vehicle speed information were input signals to vehicle control system.

3. VEHICLE CONTROL SYSTEM

Fig.4. shows the control system applied for vehicle control.

The control algorithm was based on fuzzy control principles. Fuzzy vision matrix and vehicle speed were input variables and stearing angle and motor voltage, which was directly proportional to the motor torque, were output variables.

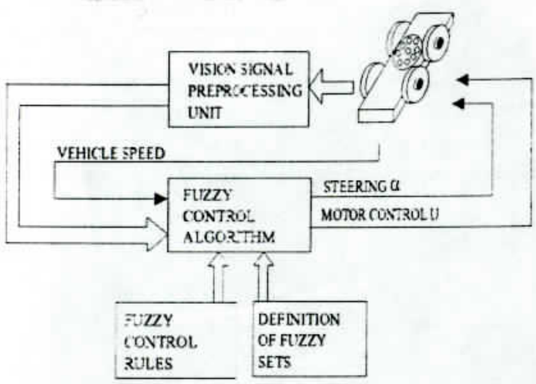


Fig.4. Vehicle contol system.

Two sets of fuzzy control rules were used:
-seven steering rules, and
-twenty-eight driving motor control rules.

The steering rules are rather simple rules having the **light position** in their "if" part and **steering angle** in "then" part. Typical example is:

"If the **light position** is FRONT-RIGHT,
than the **steering angle** is RIGHT". (2)

The motor control rules are more complicated. They have three variables in "if" part: the **vehicle speed**, the **light source distance** and the **light source direction**, and **motor voltage** in "then" part. Typical example is:

" If the **vehicle speed** is MEDIUM-TOWARD-LIGHT,
and the **light distance** is CLOSE,
and the **light direction** is HEAD,
than the **motor voltage** is NEGATIVE-SMALL". (3)

Linguistic values of variables are defined either by fuzzy matrices (light position) or by appropriate fuzzy sets (steering angle, vehicle speed, motor voltage). Light distance and light direction are calculated from the light position matrix. An example is matrix (1) which correspond to FRONT-RIGHT. As its element (1,5) has the biggest value, light distance is FAR, and light direction is HEAD. Fig.5. gives fuzzy sets definitions of the variable **steering angle**:

The fuzzy inference mechanism was classical one, based on Mamdani`s definition of fuzzy implication by operation "min" (Yi and Lan, 1989). The first step in calculation of real steering angle and real motor voltage was calculation of degrees of fulfillments of the fuzzy conrol rules "if" parts. An example for variable **light position** is:

$$DF_k = \max_{i,j}\left\{\min\left[VS(i,j), LP_k(i,j)\right]\right\} \qquad (4)$$

where DF_k is the **degree of fulfillment** of the k-th rule, VS(i,j) is (i,j)-th element of the real fuzzy vision matrix and $LP_k(i,j)$ is (i,j) element of the fuzzy vision matrix which defined the "if" part of the k-th rule. For exaple for rule (2) matrix LP_k is given by (1).

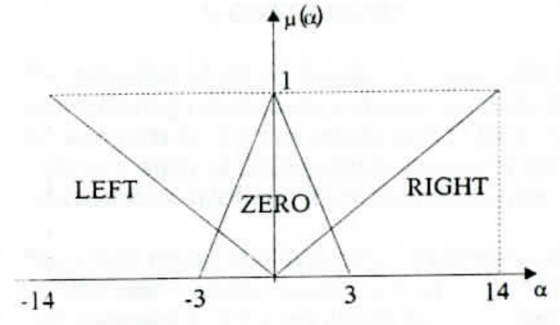


Fig.5. Fuzzy sets definitions of the variable steering angle.

Implication is defined by operation "min" and final output fuzzy set by operation "max". For steering angle the equation is:

$$OSA(\alpha) = \max_{k}\left\{\min\left[DF_k, SA_k(k)\right]\right\} \qquad (5)$$

where OSA is **output steering angle**, DF_k is **degree of fulfillment** of the k-th rule and SA_k is **steering angle** fuzzy set of the k-th rule. For rule (2) SA_k is RIGHT and it is shown on Fig.5.

Final, real value of the output variables is calculated by the "mean-value method" (Li and Lan, 1989). For steering angle the formula is:

$$\alpha_0 = \frac{\int_\alpha \alpha \cdot OSA(\alpha)}{\int_\alpha OSA(\alpha)} \qquad (6)$$

The algorithm for motor voltage were a little bit more complicated, but the principles were the same.

4. EXPERIMENTS

Our experimental vehicle shown on Fig.6. was equiped with two DC motors, one for steering and one for generating driving force. The length of the vehicle was 0.3 m, mass 1 kg, wheel radius 0.033 m and the axis distence 0.208 m.

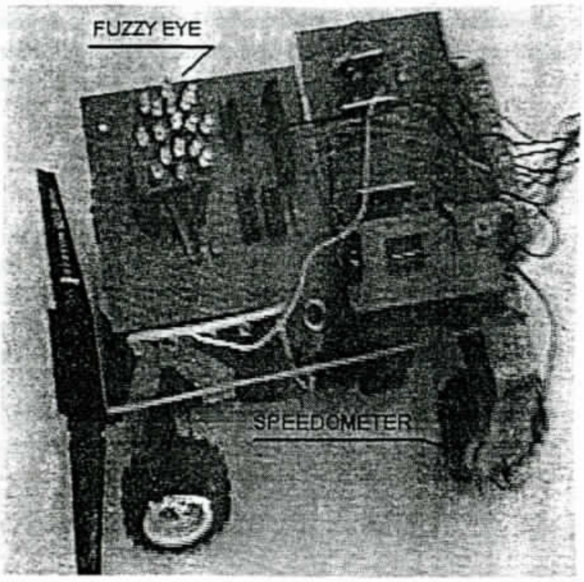


Fig.6. The experimental vehicle

The vehicle and the fuzzy eye were connected by wires to control computer based on ordinary 286/20 MHz PC compatible. All control algorithms were writen in Pascal.

The maximum steering angle was ∓ 14 degrees, and the vehicle maximum speed was 2 m/sec when 5 V was applied to the driving DC motor.

Experiments were quite sucessful, as Fig.7. shows. First three images are sequence of vehicle movements during light following. The forth image is composed image which integrate previous images.

5. CONCLUSION

The principles of rather simple, but quite effective light following vehicle control system was described. Its main parts were vision sensor called "fuzzy eye" made as a coppy of the apposition compound eye of insects, and the rule based fuzzy control algorithm.

Theoretical results were tested by experiments using DC powered vehicle model equiped with "fuzzy eye" composed by 17 photo diodes. It is important to emphasise that described vision sensor has no moving parts, and that the same principles could be used for another kind of sensors too, almoust without any modifications.

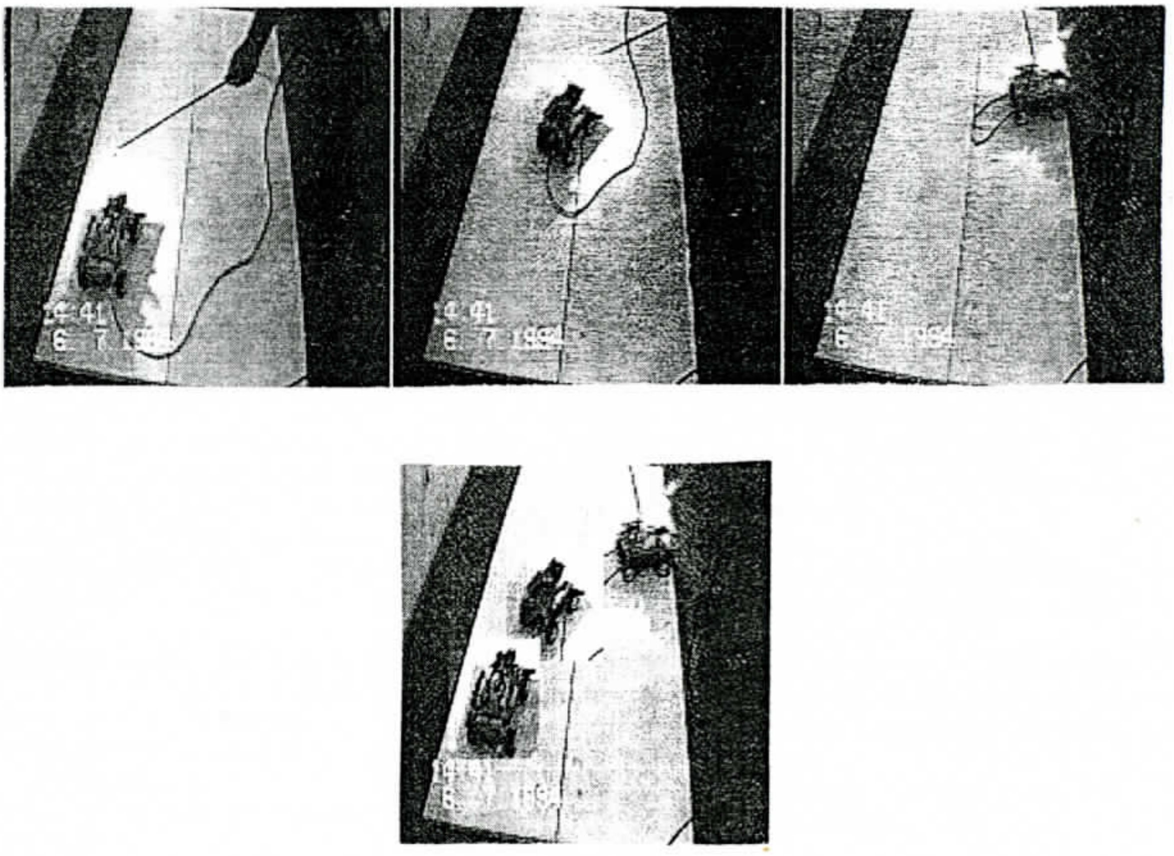


Fig.7. The sequece of vehicle movements during light following

Instead of visible photo-diodes, infrared sensors or directed microphones could be used, so heat or sound tracking system could be constructed.

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