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Foreword by the Honorary Chairman

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The decade of the nineties is witnessing a significant paradigm shift in the methodologies of systems analysis, decision analysis, optimization, information processing and control.

The shift in question reflects

- the rapidly growing power of PC's and work stations to process large volumes of information at high speed and low cost
- the improvement in man-machine interfaces
- the emergence of effective ways of dealing with complex, large-scale systems through the use of fuzzy logic (FL), neural networks (NN), probabilistic reasoning (PR) and other techniques which may be referred to collectively as soft computing (SC).

Viewed as branches of soft computing, FL is concerned mainly with imprecision, NN with learning and PR with uncertainty. There are substantial areas of overlap between FL, NN, and PR, and in many cases they can be used to advantage in combination.

The use of soft computing -- and especially fuzzy logic -- is leading to the development of numerous consumer products, industrial systems, development tools and expert system shells which exhibit a high level of MIQ (Machine Intelligence Quotient). The growing presence of high MIQ systems is likely to have a profound impact on the course of technological development in the years ahead.

The EUFIT '93 Conference is intended to provide a forum for the presentation of new ideas and results bearing on the conception, analysis and design of high MIQ systems which can make intelligent decisions in an environment of uncertainty and imprecision.

Different disciplines contribute to these developments and they will also benefit directly or indirectly from new, intelligent techniques. Hence, I welcome scientists and practitioners from many different countries and different areas here in Aachen for the First European Congress on Fuzzy and Intelligent Technologies.

L. A. Zadeh

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EUFIT ' 93 - First European Congress on Fuzzy and Intelligent Technologies, Aachen, September 7 - 10, 1993

VISION BASED FUZZY SERVO CONTROL

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Abstract: The paper presents light tracking fuzzy servo controller based on a simple vision sensor called "fuzzy eye". The "fuzzy eye" was inspirited by the compound eye of insects and conceived such that it could be easily incorporated in fuzzy control system. In this paper the application of the "fuzzy eye" in light tracking fuzzy servo controller is described and illustrated by experimental results.

I. Introduction

Since its first application in 1974. fuzzy control has been developed considerably and applied in control of various processes and devices. Although many variations to fuzzy control algorithm has been purposed the original Mamdani's ideas has not been changed a lot. Fuzzy rule base, inference mechanism, fuzzufication and defuzzufication units are still the most important parts of almost every fuzzy control system.

Usually the input part of the fuzzy controller consists of a conventional sensor, its appropriate process input interface and fuzzification unit which converts the sensor real signal into a form suitable for further fuzzy processing. In most cases this from is a fuzzy singleton - the fuzzy set having only one support element with membership value different from zero and equal exactly to one. The next step is usually calculation of degrees of fulfilment, to find which one of the input fuzzy sets of fuzzy control rules is the best satisfied with this fuzzy singleton. After that it is easy to calculate weighted output fuzzy sets, to join them in one compound control output fuzzy set and then to evaluate appropriate real control action using one of the interpretation methods.

At the beginning of our research our main idea was to change the first part of the fuzzy control procedure and directly integrated sensor in fuzzy controller. Our intention was to conceive the sensor whose output can be easily interpreted, not as a fuzzy singleton, but as a complete fuzzy set. On such a way the information about observed variable values could be generated with different degrees of precision. If the observed signal is far away from its desired value, the sensor's output could be quite non precise, but as it approaches to its desired value its precision must increase. We were particularly interested in vision based control tasks. In collaboration with Universite Chatolique de Lovain, Lovain-la-Neuve, Belgique and their project D.E.S.I.R.E. (Dynamic Expert System in Robotics Experimentation) our interest was "eye-hand co-ordination" whose control task was to position the pointing device in direction of the point light source located anywhere on a sphere around the vision sensor and the pointing device.

Later, starting a new project "Intelligent System for Underwater Data Acquisition and Processing" supported by Ministry of Science of Republic Croatia, we have defined the control task more generally. Let as suppose that we have a vehicle (land, underwater or air) whose task is to "see" the point light source when it enter in its visual field, to detect its location and then to follow it. When the light source is far away from the vehicle, it is not necessary to be very precise and to known exactly its position, but as the vehicle approaches the light source, the precision have to be increased.

Idea of integrating vision sensor with fuzzy control algorithm, seems to us quite appropriate. The first problem was the choose the vision sensor. For such a control task CCD video camera is too complex, specially because its vision signal processing is relatively complicated and time consuming. As Nature is unlimited source of inspiration we turn our attention to Nature and try to find a living creature who has similar control task as our vehicle. Is was not difficult to find such an animal. The house fly behaves quite similarly. Many times in my life I have used the ability of the house fly to detect the light source and to fly toward it. When I wanted to push away the fly from my flat without killing the insect it was sufficient to open the window, to turn off the lights in the apartment and to turn on the light on the balcony. Every time I was amazed how quickly the fly had "seen" the light and flown toward it. And for such a control task the fly does not need a complex lens eye whose man made copy is a video camera. For such a task a simple insect eye usually called the compound eye was quite sufficient

From the study of insect compound eye [1] the idea of simple vision sensor called "fuzzy eye" was born, and described for the first time in 1991 [2]. Fuzzy eye was conceived as an array of light-sensitive elements (photo detectors) arranged on a way that quite simple analysis of electric signals generated by them is sufficient to detect the light source position. This vision signal transformed into a from of fuzzy matrix then could be used as a direct input to a fuzzy controller. Fig.1. shows cross sections of the insect compound eye and our simple vision sensor - the "fuzzy eye".

Our sensor is called "fuzzy eye" because of two things:

- the image captured by it is rather non precise and fuzzy, and
- fuzzy set theory could be directly applied for its vision signal processing and analysis.

The application of this simple vision sensor in control system based on principles of eye-hand co-ordination was described in [3]. The analysed system was combined of an "eye" (simple linear five element fuzzy eye) and a "hand" (DC motor driven pointing device), as Fig.2. shows. Each of them could rotate independently and the control task was to point with the pointing device to the light source positioned on a semicircle around the fuzzy eye and the pointing device.

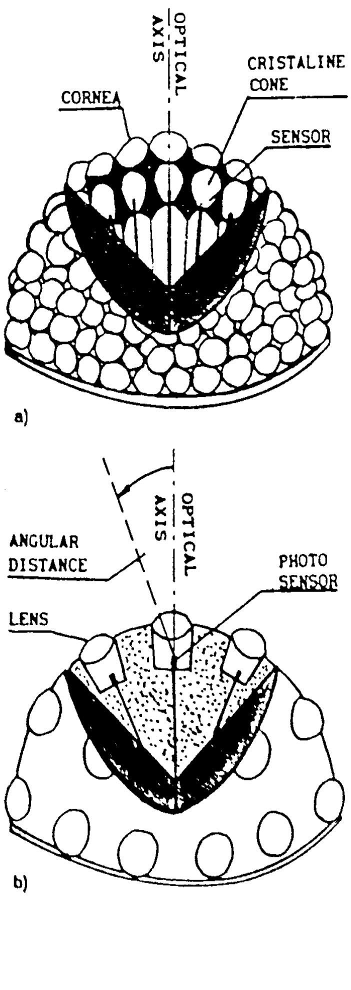


Fig.1. Cross section of the insect compound eye (a) and the simple vision sensor called fuzzy eye (b)

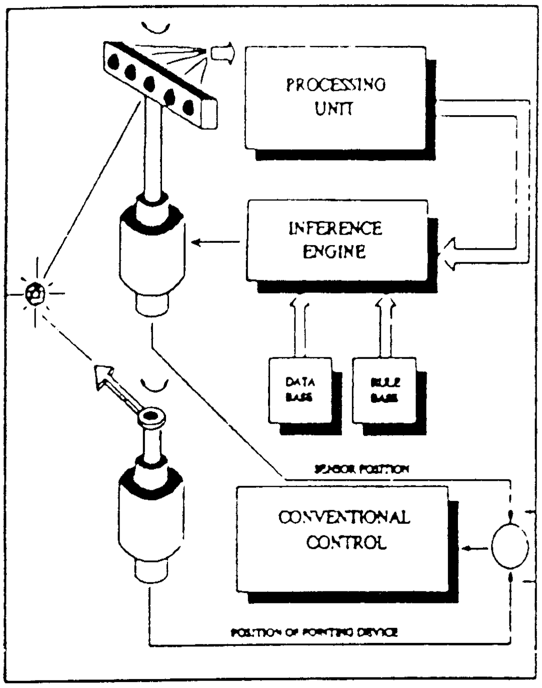


Fig.2. Fuzzy position control based on eye-hand co-ordination.

A simple fuzzy control algorithm having only three control rules was used. Simulation results [3] where quite satisfactory and encouraging. Because of that we have continued our research and in this paper further development of the vision based fuzzy control is described. In our new research we have:

- used more universal two dimensional hemispherical fuzzy eye instead of a simple linear fuzzy eye used previously,
- the control task was not to position the pointing device, but to position the sensor itself in direction of the light source, and
- the system was not analysed by simulations, but the real life experiments were performed.

In the rest of this paper our experimental set-up, fuzzy control algorithm principles and obtained results will be shortly described.

II. Light tracking fuzzy servo controller

Our experimental set-up is shown in Fig.3. The system consists of the vision sensor, pre-processing unit, I/O interface, PC based computer with 286 processor and DC motor servo system. Fig.4. shows the actual view of the vision sensor mounted on the pre-processing board and DC motor servo system position control board.

The vision sensor is made up of 17 photo detectors. The voltage generated by each photo detector is the greatest when the angular distance between the incoming light and photo sensor optical axe is zero, and it rapidly decreases as the angular distance increase. The photo detectors are arranged in the shape of a sphere, such that each detector covers one part of the space, and all 17 detectors cover the whole space above the sensor.

When the point light source is turned on somewhere in this hemispherical space, photo detectors generate different voltages. Their magnitudes depend of the relative position of the light source and the photo detectors. After normalisation these signals are arranged into a from of fuzzy matrix and directly used as a input to a fuzzy controller. The control task was to rotate the fuzzy eye until its previously defined front end is oriented toward the incoming light.
The fuzzy control algorithm was based on eight simple control rules given in Table 1.

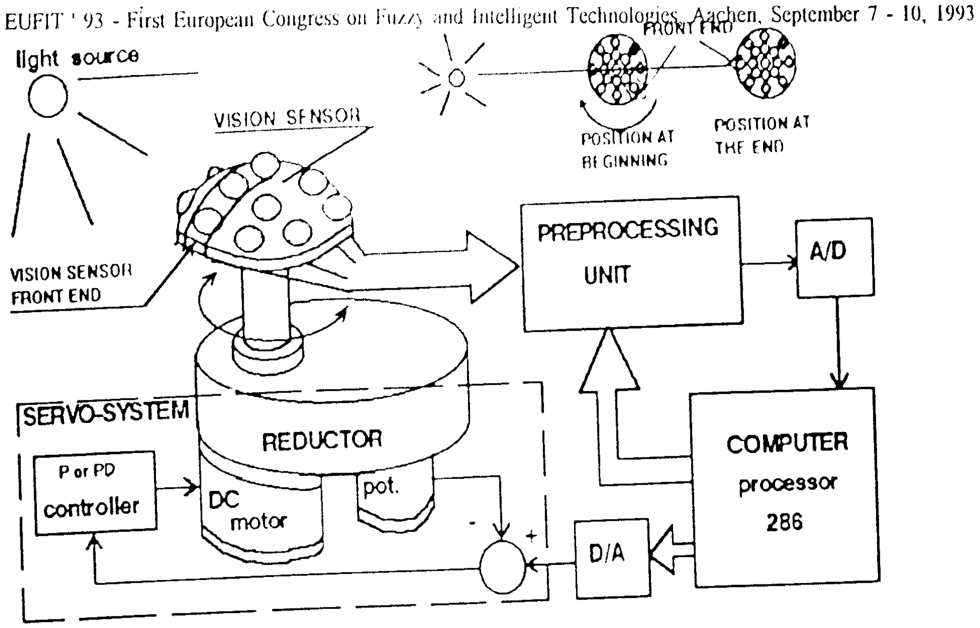


Fig.3. Experimental set-up for vision based servo control

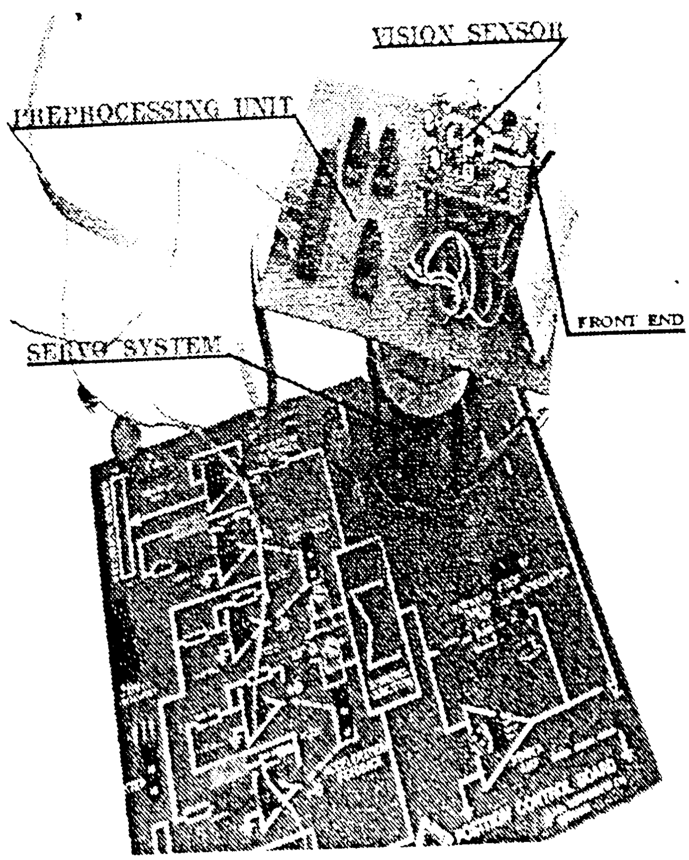


Fig.4. Vision sensor, pre-processing unit and DC motor servo system

Table I. Control rules of fuzzy controller

k	1	2	3	4	5	6	7	8
Light position	FRONT	FRONT LEFT	LEFT	BACK LEFT	BACK	BACK RIGHT	RIGHT	FRONT RIGHT
Control change	ZERO	NEG. SMALL	NEG. MEDIUM	NEG. BIG	NEG. BIG	POS. BIG	POS. MEDIUM	POS. SMALL

Linguistic forms of control rules are IF-THEN sentences, for example for the 1st rule.

"IF the light is positioned *front left*, THEN the reference control signal have to be changed *negative small*"

Front left is, the same as *front, left, back left, back, back right, right and front right,* two dimensional discrete fuzzy set (fuzzy matrix) used to define the position of the light source according to the vision sensor. An example, for the light position *front* is

$$P_1(i,j) = \begin{bmatrix} 0.2 & / & 1 & / & 0.3 \\ / & 0.4 & 0.45 & 0.3 & / \\ 0.1 & 0.33 & 0.1 & 0.3 & 0.2 \\ / & 0.15 & 0.15 & 0 & / \\ 0 & / & 0 & / & 0 \end{bmatrix}$$

It is easy to notice that this fuzzy matrix is not symmetrical. The reason is because it was not possible to made the sensor symmetric, so we have decided to define light position matrices using results of measurements. The light source was placed at eight reference positions and corresponding vision sensor's fuzzy matrices were used as $P_k(i,j)$. Matrix elements marked with / means that these places was not covered by appropriate photo detectors, because our experimental sensor was made of 17 detectors only. *Zero, negative small, negative medium, negative big* and the same for positive, are fuzzy sets of servo system referent position change defined by 13 element fuzzy vectors. An example for referent position change *zero* is

$$R_1(\ell) = [\,0\ 0\ 0\ 0\ 0\ 0.5\ 1\ 0.5\ 0\ 0\ 0\ 0\ 0\,]$$

Support set of these fuzzy vectors is the set of integers $S = \{s_\ell\} = \{ -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6 \}$.

The calculation procedure is quite simple. In each discrete time moment nT the vision fuzzy matrix $O(i,j)$ is compared with all eight light position reference fuzzy matrices $P_k(i,j)$ and appropriate degrees of fulfilment γ_k are calculated:

$$\gamma_{k,n} = \max_{i,j} \,[\, \min\,(O(i,j)_n, P_k(i,j))] \qquad (1)$$

After that the output fuzzy set of servo system referent position change is obtained as

$$R(\ell)_n = \max_{k} \,[\gamma_{k,n}, R_k(\ell)] \qquad (2)$$

and at last, the centre of gravity is used as interpretation method, giving as a result the real value of referent position change in interval [-6,6]:

$$R_n = \sum_{\ell=1}^{13} R(\ell)_n \cdot s_\ell \,/\, \sum_{\ell=1}^{13} R(\ell)_n \qquad (3)$$

The new referent position of DC servo system is calculated as

$$U_n = U_{n-1} + K \cdot R_n \qquad (4)$$

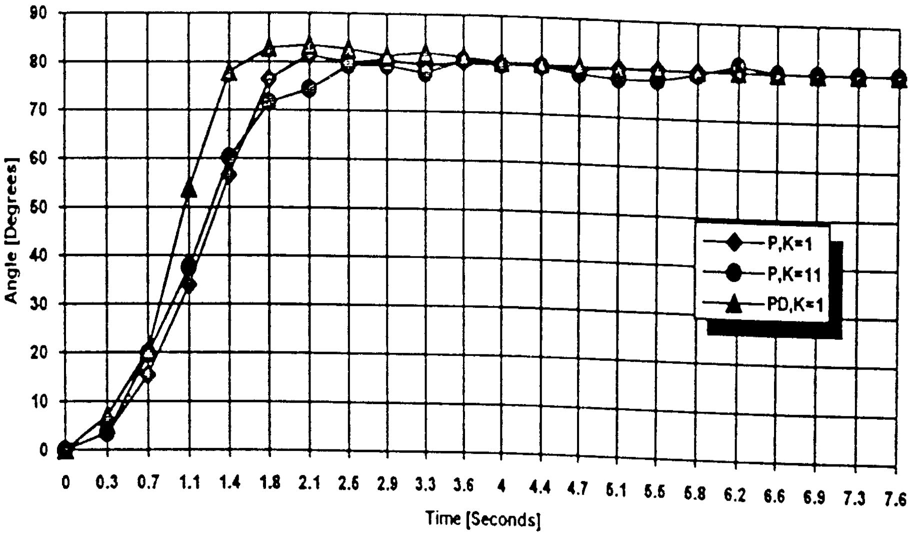
U_{n-1} is referent position in previous discrete time moment and K is the output controller gain simply defined as $K = \Delta U_{max}/6$, where ΔU_{max} is maximal referent position change. In our case ΔU_{max} was 2.5 V.

Important is to mention that fuzzy controller parameters were not specially tuned. Control rules and referent position change fuzzy vectors were created "ad hoc" using only common sense, and light position fuzzy matrices $P_k(i,j)$ were defined using results of simple experiments.

III. Experimental results

The computer used in experiments was standard 16 MHz 286 based PC compatible equipped with input multiplexer and cheep 8 bit A/D and D/A converters. Inspire of its simplicity the control system behaviour was quite satisfactory. Fig.5 shows system response for proportional servo control with two different proportional gain values and for PDservo control. The referent signal change was calculated approximately every 0.4 seconds and the light was located 80 degrees right from the referent fuzzy eye position.

SERVO SYSTEM RESPONSE



SERVO SYSTEM REFERENT POSITION

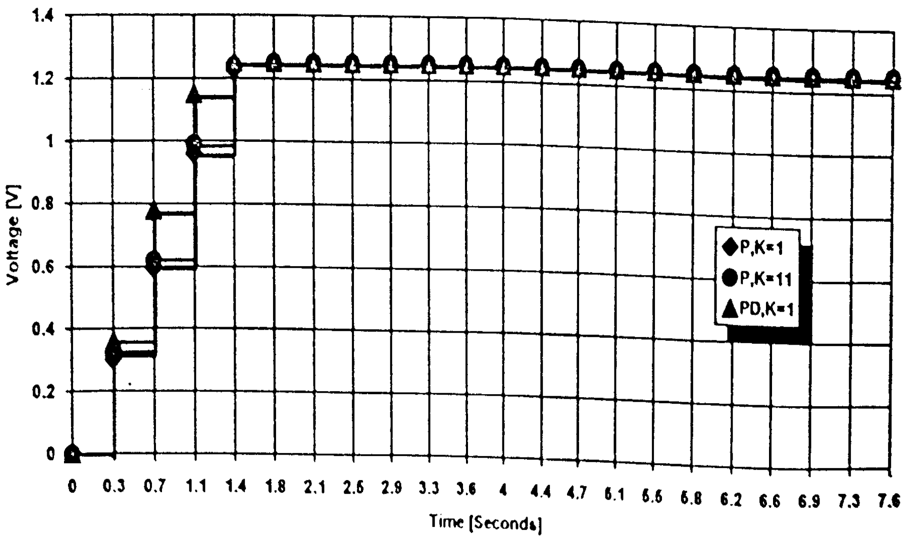


Fig.5. System responses for different servo system controllers

Fig.6. shows vision signal fuzzy matrices at the beginning and at the end of movemet

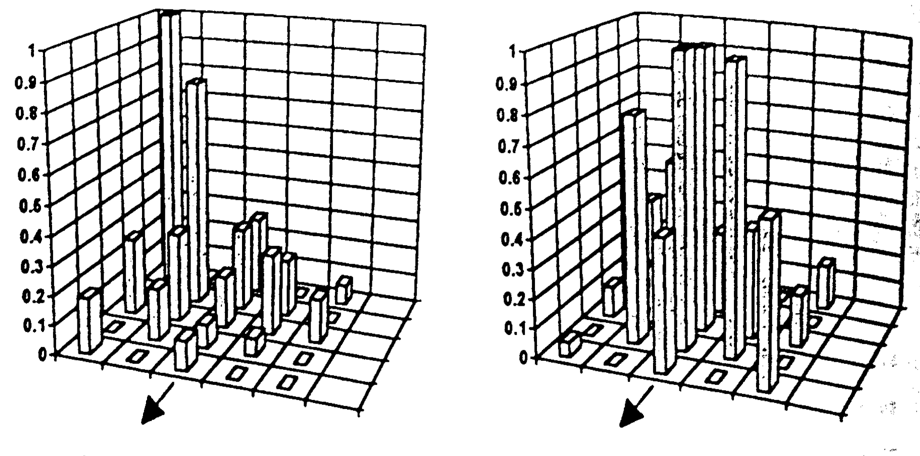


Fig.6. Vision signal fuzzy matrices at the beginning and at the end of movement

We have performed lot of experiments and in all cases control system behaviour was similar and quite acceptable. Important is to mention that the same principle could be used with other kind of sensors, too. For example, using thermal, sound, magnetic or chemical sensors, appropriate, simple and effective heat, sound, magnetic field or smell tracking servo controller could be constructed.

IV. Conclusions

The light tracking control system based on a simple vision sensor called "fuzzy eye" and fuzzy control algorithm is described and illustrated with experimental results. Its main advantage is its simplicity, both in vision sensor construction and fuzzy control algorithm structure. Inspire of that its features are quite satisfactory. The vision sensor visual field covers the whole upper hemisphere, and the system response is rather good, both in speed and accuracy of response. Although we were quite satisfied with experiment results they could be even better, because we have not used all "fuzzy eye" potentials. Its construction is adjusted for parallel signal processing, particularly in calculation of degrees of fulfilment, so we will continue our research in that direction.

V. Acknowledge

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VI. List of references

[1] J.N.Lythoe, The Ecology of Vision, Clawedom Press, Oxford, 1979.

[2] D.Stipaničev, Fuzzy vision and fuzzy control, Proc.of 13th IMACS World Congress on Computation and Applied Mathematics, July 22-26, 1991, Dublin, pp.1210-1211

[3] D.Stipaničev, M.Cecić, Eye-hand co-ordination based on fuzzy vision transducer, Proc. of FUZZ-IEEE'92, San Diego, USA, March 8/12, 1992, pp.29-35