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Fuzzy vision and fuzzy control

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Abstract

Vision sensor called fuzzy eye is introduced. It is conceived as an array of light-sensitive elements (photo detectors) arranged on a way that quite simple analysis of signals generated by them is sufficient to find the approximate position of light source according to the eye position. This information could be then directly used as an input to a fuzzy control unit whose task is to find and to follow the light source. The fuzzy eye was inspirited by the apposition compound eye of insects.

1. INTRODUCTION

Fuzzy control had its origins in fuzzy set theory, with the first publication appearing in the early 1970's. Since then, the field has maturated considerably, with applications and theoretical work being reported from all over the world. In the last couple of years there are two main streams in the field of fuzzy control. The first one is orientated toward commercialization of simple fuzzy control principles and its industrial application, and the second one deals with theoretical and experimental development of more sophisticated form of fuzzy control. This paper belongs to the second group and deals with theoretical development of vision sensor based fuzzy control system.

Motivation for this research came from two sides. The first one was development of fuzzy transducer [1], an intelligent measuring device which consists of a sensor and the inference engine and gives measuring signal in a form suitable for human perception and observation. With intelligent interpretation of measuring signals it is possible to use simple, non expensive sensors in measurement of quite complicated phenomena. On the other side, in the field of robotics, sensor guided robot manipulators and vehicles become more and more important, even from commercial point of view [2]. For such applications vision sensor is maybe the most important one. We have tried to connect ideas of fuzzy transducer and vision guided control system and to develop a simple vision sensor called fuzzy eye and a control system based on it.

Our particular interest was "eye-hand coordination" what means the control of robot's hand or the whole robot vehicle using information received from the vision sensor (robot eye). The most simple task was to find and to follow the light source in one, two or three dimensions, but we have started this research having in mind more sophisticated vision based control tasks. Typical examples are manipulation with recognised objects, or avoiding obstacles by remotely operated vehicle (ROV) in unknown underwater environment.

Inspiration for our research came from Nature. In insect kingdom a vision sensor called compound eye could be encountered. It is quite simple in construction, but powerful enough for lot of control tasks based on "eye-hand coordination", or in their case better called "eye-body coordination".

The principles underlining this paper could be used for other kind of sensors, almost without any modification. Instead of visible light photo-sensors, infrared sensors or acoustic sensors could be applied and heat based control or sound based control developed.

2. FUZZY VISION BASED CONTROL

The process of vision naturally has three stages [3]: the optical stage when an image of the outside world is projected on the retina, the transduction stage when the light-sensitive visual cells absorb photons and respond by generating electrical signals and

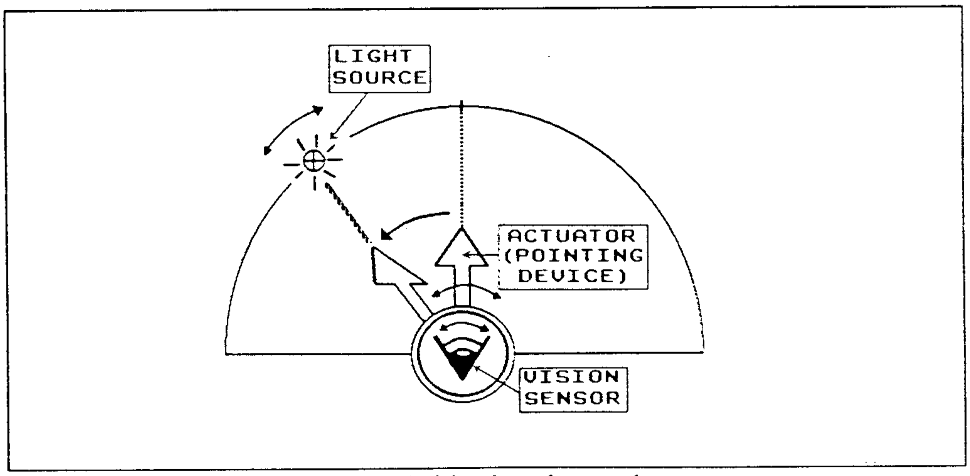

Figure 1. Eye-hand coordination and vision based control

the physiological stage when these primary signals are analyzed. Idea of the fuzzy vision is primarily connected with the second and the third stage. Fuzzy vision sensor (fuzzy eye) is conceived as an array of a light-sensitive elements (photo detectors)

arranged on a way that quite simple analysis of electric signals generating by them is sufficient to detect the light source position. This vision signal could be then used as an input to the control system. Our main interest was robot control based on the principles of "eye-hand coordination".
Generally the geometry of a vision sensor, the eye, is quite different for the night vision eye which require an image of a point source of light and the eye of the extended bright field that normally is encountered by diurnal animals. Fuzzy vision based control, described in this paper is developed for the first case when the main control task is to see and then to follow a point source of light, such as a lamp or a small luminescent object on a dark background. For one dimensional case this means to find and to follow the light source positioned on the circle around the vision sensor. Fig.1. shows this situation schematically. In the center of the circle are both, the vision sensor and the actuator (pointing device). The final goal is to position the pointing device in the direction of the light source. In two dimensional case instead on a circle, the light source could be positioned on a sphere, and in three dimensional case, the light source could be anyway in the space.

3. FUZZY EYE

The nature is unlimited source of ideas, so the inspiration for the fuzzy eye come

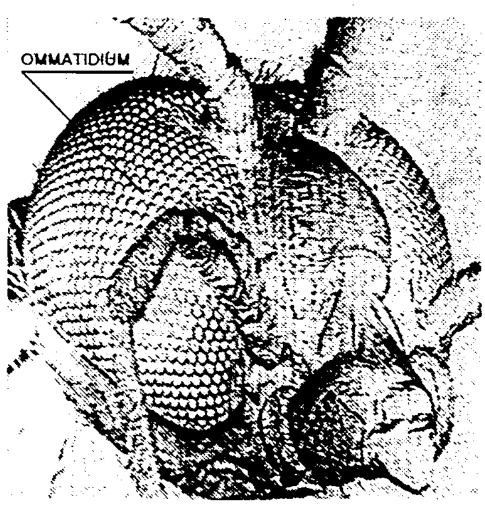

Figure 2. Insect compound eye

from the nature, too. In animal kingdom two types of eyes could be encountred, a quite complicated lens eye of vertebral animals and a simple compound eye of invertebral animals. A lens eye has a rather complex optics and the internal image created by it could be used for complex vision based tasks, because the vertebral animals have a quite complicated life behaviour. On the other side there is a world of insects, the biggest group of invertebral animals, whose behavior is quite simple, but rather efficient. They are highly specialised. Some travel at high speed and make rapid turns, other fly straight and hover, third remain motionless for hours, but all of them rely for their survivel on vision, based on many-faceted compound eyes. The insect eye construction is always the same and quite simple, but the geometry and features of the compound eye is adopted to insects different habits and visual requirements.

The man made copy of a lens eye is a video camera. The camera lens correspond to the eye lens and CCD sensor to the eye retina. In this paper we have proposed for the first time a man-made copy of the insect compound eye and we have called it *fuzzy eye*. The name "fuzzy eye" is used because:

(i) the image captured by it is a rather fuzzy, and

(ii) fuzzy set theory could be easily applied for analysing and transforming its image for further processing and control applications.

The insect compound eye is made up of ommatidia [3,4] as Fig.2 shows. Ommatidia

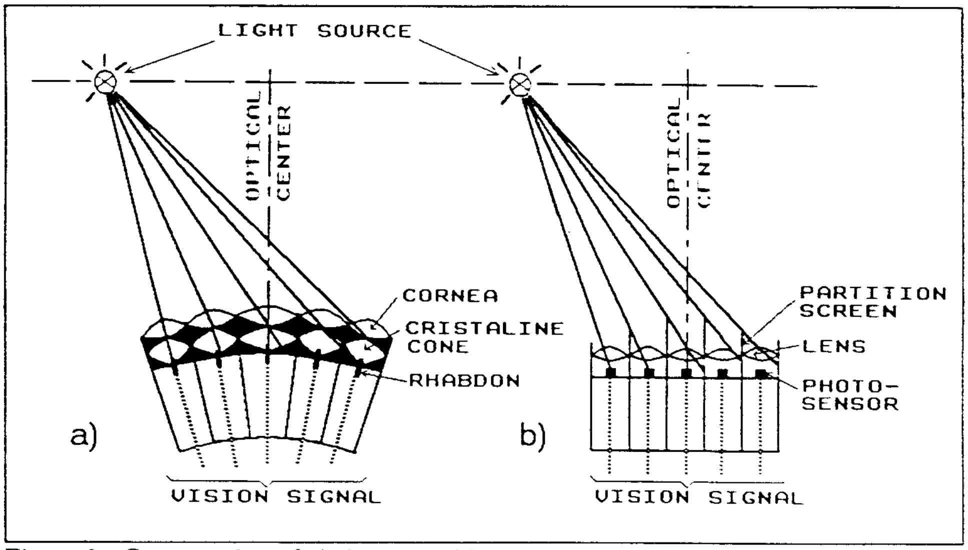

Figure 3. Cross section of a) the apposition compound eye and b) the fuzzy eye

are tiny individual eyes that point in different directions. Each of them consists of a cornea that focuses light through crystalline cone on a light-sensitive organ known as a rhabdon. Light absorbed by the rhabdon transmits a vision signal to the insect's brain through the optical nerve. Fig.3a. shows the cross section of a compound eye where each ommatidium is a single sampling element with its own optical axis. Such compound eye is known as apposition compound eye [3]. Another kind of compound eye is a superposition compound eye where a group of ommatidia act together and focus light onto a single rhabdon. Fuzzy eye is a man made copy of the apposition compound eye,

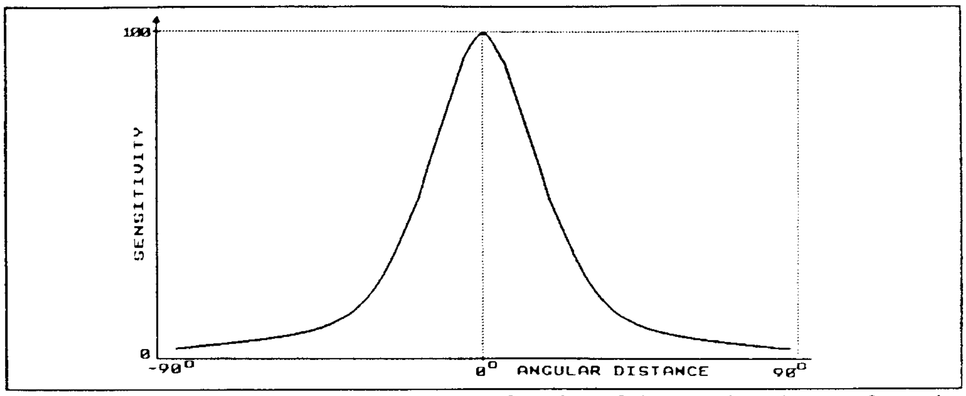

Figure 4. Sensitivity of the photo sensor as a function of the angular distance from the sensor's opical centre

so only this kind of compound eye will be discused here.

The optical axis of the ommatidium is the line extending through the center of the lens to the rhabdon. Sensitivity of the ommatidium decreases with angular distance from its optical axis. The amount of light that rhabdon receives is the biggest when the angle between light and ommatidium optical axis is zero. As this angle increases amount of light rhabdon receives decreases rapidly. The field of view of each of the ommatidia usually is defined as the angle subtended where the sensitivity has fallen to 50% of its maximum value. Ommatidia are arranged such that each one "covers" one part of the space. When the light is positioned in its part of the space the vision signal of that ommatidium is the biggest, but other ommatidia in its vicinity are excited, too. As a result the vision signal received from a set of ommatidia carries information about the position of the light source.

The structure of the fuzzy eye is quite similar to the structure of the apposition compound eye, as Fig.3b. shows, but fuzzy eye has some additional features. Fuzzy eye consists of light sensitive elements - photo detectors. Each of them is constructed on a way that lens is encapsulated together with the sensitive element. Sensitivity of such sensor also decreases with angular distance from the photo detector center line (optical axis), similarly to the sensitivity of the ommatidium. Even the shapes of both natural and man-made light sensors sensitivity curves are qualitatively very similar. They are both bell like curves which could be mathematicaly modelled as "versiera" Marie Agnesi. A typical sensitivity curve is shown on Fig.4. The angular distance between the light and the sensor's optical center is ploted on x-axis and the relative sensitivity on y-axis.

Additional feature of the fuzzy eye came as a result of introduction of partition screens between photo detectors. These screens have a strong influence on the shape of the vision signal. Changing the screen height it is possible to give more or less importance to some photo sensors., and to change its "responsable" part of the space.

For example, partition screens shown in Fig.3b. limit the space in which the central sensor could "see" the light source. If the light moves slightly away from its optical centre, the generated voltage will decreases rapidly, and it will fall almost to zero.

The vision signal carries information about the light source position. This position is given relatively according to the optical centre of the eye. For the case shown in Fig.3b. the intensity of the signal produced by the sensor on the left will be the biggest and the last three sensors on the right will not be affected by the light. The signal generated by the five element linear fuzzy eye could be expressed by the five element vector, for example u = [88 44 0 0 0], where 88 is a voltage in mV generated by the first sensor from the left, 44 mV is generated by the next one, and so on. After normalisation this vision signal could be represented by the vector [1 0.5 0 0 0], whose elements take values in interval [0;1]. Numbers represent relative intensity of the each sensor signal, normalised according to the biggest value. This vector carries information about light source position and it could be seen and analyzed as a fuzzy vector. Its support set could be defined as a set of discrete angular distances from the

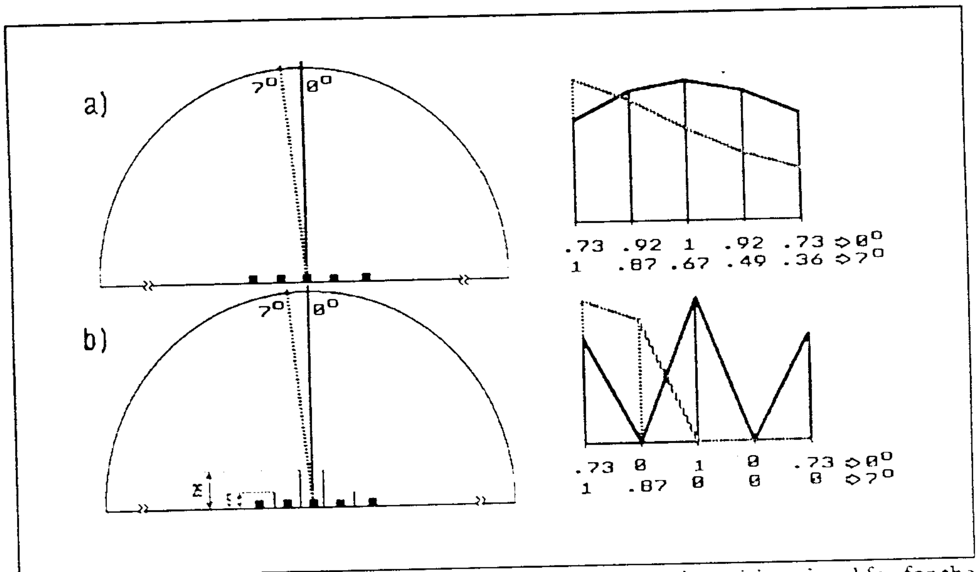

Figure 5. Geometry of simulated linear fuzzy eye and appropriate vision signal for for the eye without and with partition screens

fuzzy eye optical centre { $-\psi_V$, $-\psi_W$, 0 , ψ_W , ψ_V }. Now, particular values could be interpreted as degrees to which the light source could be positioned more or less close to the appropriate angular distance landmark. For previous example the angular position between the light ray and fuzzy eye optical centre is $-\psi_V$ with degree 1, $-\psi_W$ with degree 0.5 and so on. In two dimensional case instead in a form of the fuzzy vector, the vision signal could be expressed and analyzed as a fuzzy matrix, and in three dimensional case and binocular vision the vision signal consists of two fuzzy matrices. Fig. 5. and Fig. 6. shows results of simulation of one dimensional (linear) and two dimensional fuzzy eyes.

In the first case fuzzy eye consisted of 5 photo sensors positioned 5 mm each from the other, and in the second case 25 photo sensors were positioned on the sphere segment whose radius was 30 mm and height 25 mm. Diffraction effect at the edges of the photo sensor's lens (Airy pattern) [3] was neglected, because each photo sensor was modelled as a point photo sensor. The sensitivity curve of each photo sensor was modelled by "versiera" Marie Agnesi and defined by the equation $S(\alpha) = 10000/(100+\alpha^2)$. S is the relative sensitivity in % for a distance fixed at 100 mm, and α is the angular distance from sensor's optical centre.

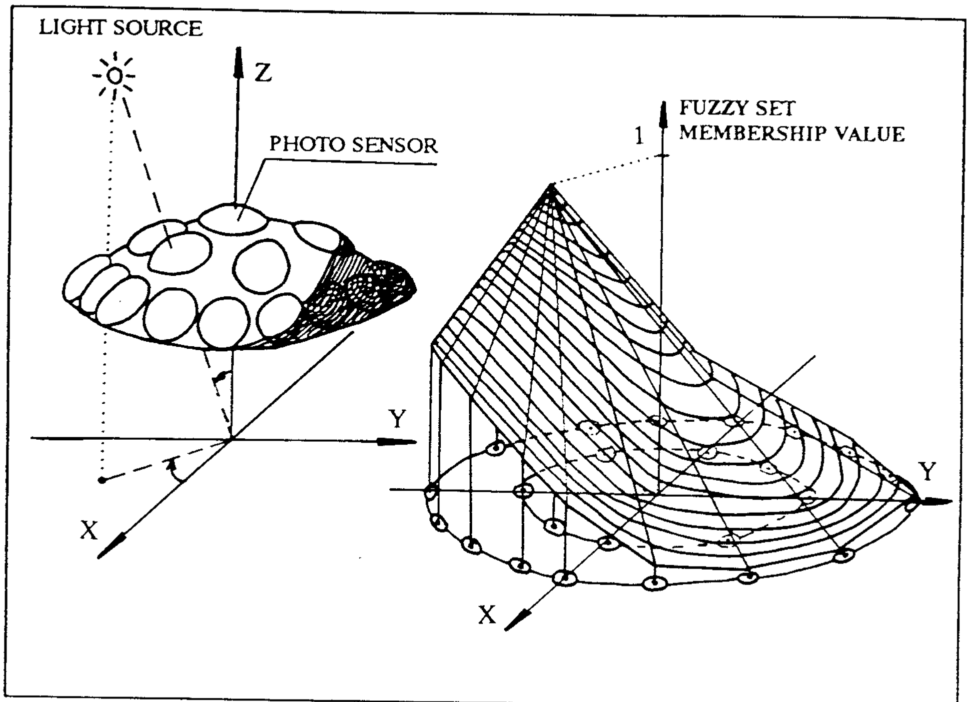

Figure 6. Geometry of simulated two dimensional fuzzy eye and its appropriate vision signal

In the case of linear fuzzy eye two situations were simulated. The first one was for fuzzy eye without partition screens and the second one for a certain combination of screen heights. Light was positioned at the optical centre and 7 degrees left of the central line. The influence of the partition screens is evident. In the case of two dimensional fuzzy eye, schematically shown in Fig. 6a, only a situation without partition screens was simulated. The light was positioned -45 degrees left from the x axis in xy plane and 45 degrees from the z axis, and appropriate vision signal is illustrated in Fig.6b.

These vision signals, in the form of fuzzy vectors or fuzzy matrices, could be directly used as inputs to fuzzy controller, whose task is to control the fuzzy eye and pointing device movements.

4. FUZZY VISION BASED FUZZY CONTROL

As an example of fuzzy eye application in vision based control tasks, the position control of the pointing device, based on principles of "eye-hand coordination" will be shortly described. More details could be find in [5] and other possible fuzzy eye applications in [6].

The main control task in pointing device position control is to find and to follow the light source. For static light the pointing device has to be positioned in direction of the light source as Fig.1. shows. One possible solution, based on "eye-hand coordination", suppose that both, the fuzzy eye and the pointing device, have independent motors, so each one can rotate independently. When the light turns on the fuzzy eye produce vision signal in the form of fuzzy vector or fuzzy matrix. From the shape of its membership function it is possible to determine the approximate position of the light source. This fuzzy information is then used as an input to rule base fuzzy controller which controls direction and velocity of fuzzy eye rotation. The control algorithm (control rules) are such that the eye will stop rotating when its optical centre intersects the light. Pointing device starts to rotate at the same time as fuzzy eye, but pointing device control algorithm take care about eye's position, too. For final, precise adjustment of pointing device precise, non fuzzy information of fuzzy eye location is used. For eye movement a simple rule base with only three rules have been used, and results reported in [5] were more than satisfactory.

5. CONCLUSION

In technical world simplicity of solution is an advantage. That was our motive in development of this simple vision sensor called fuzzy eye. The inspiration for the fuzzy eye come from the animal kingdom, and fuzzy eye was constructed as a man-made copy of the apposition compound eye of insects. The compound eye is an array of hundreds of small, simple eyes called ommatidia, each of them having only one light sensitive part, rhabdon, and looking out more or less equally in many directions. The advantage of such an arrangement is that it operates by parallel processing and divides external world information into many parallel channels. Thus the insect can be aware of its entire visual world at every moment, whereas animals with lens eyes (including ourselves) can gain that information only by continually moving their eyes and heads in a series of scans.

The structure of the fuzzy eye is quite similar to that of the compound eye, and instead of ommatidia simple photo sensors are used. In this moment the fuzzy eye was conceived having in mind the control task which consists of seeing and following a point source of light. The vision signal created by the fuzzy eye carries approximate, fuzzy information of the light source position. This signal, transformed into the form of fuzzy vector or fuzzy matrix is then used as an input to a fuzzy controller which controls the velocity and position of the eye itself and the pointing device which has to follow the light source.

Our further work will include further development and analysis of fuzzy eye, particularly the influence of different eye geometries on its features and application of fuzzy eye for other, more complex vision based control tasks. One of these applications could be the robotic vehicle navigation in unknown environment avoiding obstacles.

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