FUZZY VISION TRANSDUCER AND ITS APPLICATION IN CONTROL*

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Abstract. The simple vision sensor called fuzzy eye , inspirited by the apposition compound eye of insects is further developed and fuzzy vision transducer is proposed.It has two parts: fuzzy eye as a vision sensor and a processing unit for analysing, reshaping and transforming primary vision signals. Possible control applications of the fuzzy vision transducer are discussed, too, and illustrated by examples.

Keywords. Transducers; Sensors; Fuzzy control; Fuzzy set theory; Image processing

INTRODUCTION

Theory of fuzzy sets is today a quite widely applied mathematical approach to modelling of the imprecise signals. During the last decades it has been developed and used in various fields, but its application in measurement and observation has not yet been fully explored. Finkelstein and Ledding [1] and partly Syndeham [2] have only mentioned the possibility of fuzzy sets application in measurement. In 1988. the concept of fuzzy transducer [3] was described. It was conceived as an intelligent measuring device which consist of a selected sensor and the inference engine which transforms the measureand in the signal 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 complex phenomena. More recently [4] the fuzzy eye - a simple vision sensor was introduced and shortly analyzed.

In this paper the idea of fuzzy eye is further developed and fuzzy vision transducer based on fuzzy eye is described. Its theoretical foundations and possible applications, particularly in the field of sensory guided robotics are analyzed and explained.

It is important to emphasize that, although the "vision transducer" is analyzed and discussed here, whose main task is to find and/or to follow the visible light source, the same principles could be used for other kind of sensors and transducers too.

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Typical examples are "thermal transducer" with infrared sensors, "sound on ultra-sound transducers" with acoustic sensors, or "magnetic transducer" with magnetic field sensors.

SIMPLE VISION SENSOR AND FUZZY VISION TRANSDUCER

Vision - based control has become quite important in the last decade, specially in connection with robotics and remotely operated and autonomous vehicles. The control procedure is based on information received from vision sensor. In most cases a video camera is used as a vision sensor, but camera requires a quite complicated procedure for image capture and image analysis. On the other side in lot of these cases for a number of control tasks it is not necessary to have such a great amount of visual information captured by the video camera. Typical example is the control task when the light source have to be detected and followed.

As the Nature is unlimited source of inspirations a good idea is to turn our attention to animal kingdom and try to find how this simple vision-based control tasks are solved there. In animal kingdom two types of eyes could be encountered, a lens eye of vertebra animals and compound eye of invertebra animals. A lens eye has a rather complex construction and an image signal created by it could be used for quite complex vision based tasks, because the vertebra animals have a complicated life behaviour. On the other side there is a world of insects, the biggest group of invertebral animals, whose behaviour is simple but very efficient. These animals are highly specialized, and all of them rely for their survival on vision. Although insects visual requirements are quite different their vision is based on many-faceted compound eyes. The eye construction is always the same and quite simple, but its geometry and features are adapted to insects different habits and behaviour. One of them encountered with house-fly is detection of the light source and fly flight control toward the light. I have used this fly behaviour a lot of times when I wanted to push away the fly from my apartment and I was always surprised how quickly the fly found the light switched on the balcony. For this task the fly does not need a complex lens eye but a simple compound eye.

As the man made copy of the lens eye is a video camera, our idea was to create a simple vision sensor inspirited by the compound eye of insects. We have called it the "fuzzy eye" [4] because of two things: (1) the image captured by it is a rather fuzzy and (2) a fuzzy set theory could be easily applied for analysing and preparing this image for further processing.

The construction of the fuzzy eye is quite similar to the construction of the apposition compound eye [5], as Fig.1. shows. It could be defined as an array of the

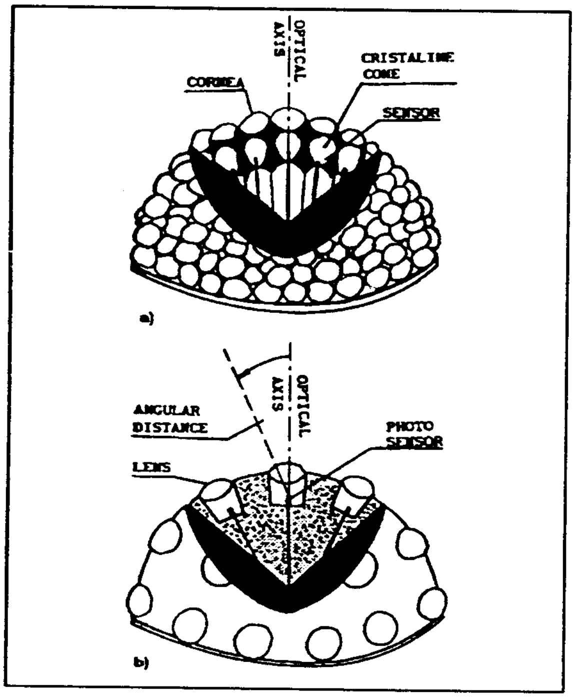

Fig.1. Cross section of the insect compound eye (a) and the simple vision sensor - fuzzy eye (b)

light sensitive elements (photo detectors) arranged on a way that each of them "covers" one part of the space. Each photo detector has a sensitivity curve which decreases with angular distance from its centre line (optical axis). The shape of the sensitivity curve is usually the "bell-like" curve (versiera Marie Agnesi). It is interesting that this shape is almost the same as the shape of the sensitivity curve of the insect eye section.

When the light source is positioned in the part of the space of one photo detector its signal is the biggest, but other photo detectors are excited, too. As a consequence signals received from the whole array of sensors (fuzzy eye) carry information of the light source position and they could be used for control tasks. But first, this signal have to be processed and prepared for further applications. That is the reason why we are here proposing a *fuzzy vision transducer* based on the fuzzy eye. The fuzzy vision transducer consists of two parts as Fig.2. shows. The first one is the fuzzy eye explained previously and the second one is the processing unit where sensor information are analyzed, reshaped and transformed into a from suitable for further processing and application in fuzzy control.

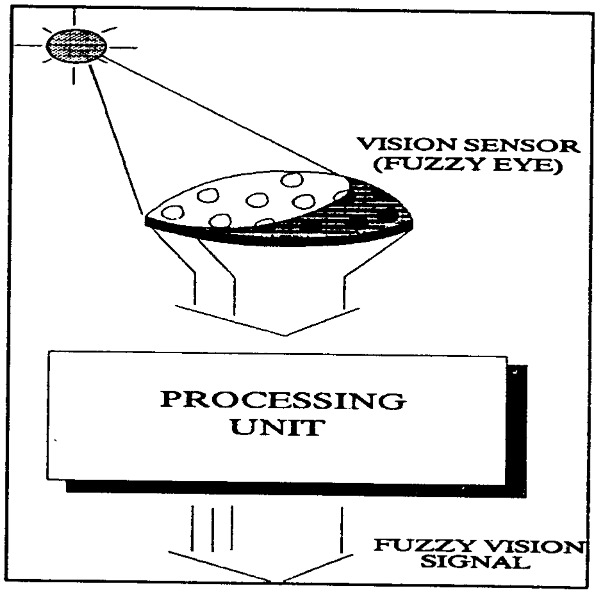

Fig.2. Fuzzy vision transducer

In one dimensional case when the fuzzy eye is conceived as a line of photo elements, this final signal is a fuzzy vector. In two dimensional case the final signal is a fuzzy matrix and in three dimensional case, when there is a binocular vision and two fuzzy eyes, the final result are two fuzzy matrices. Let us concentrate on the most simple, one dimensional case with 5 photo detectors and show how fuzzy vector could be created.

Depending of the light source position each photo detector create some voltage on its ends. The signal generated by the whole sensor could be given by a vector $u = [u_1 \ \ u_2 \ \ u_3 \ \ u_4 \ \ u_5]$ where u_1 corresponds to the left sensor, and u_5 corresponds to the right sensor.

The first step is normalisation and creation of another vector whose elements take values in unit interval [0;1]. One typical example could be u = [0.87 1 0.63 041 0.20]. This vector carries information about the light source position according to the fuzzy eye optical axis, and it could be seen and analyzed as a fuzzy vector. Its support set is defined as a set of discrete angular distances, for example $\{-\psi, -\psi/2, 0, \psi/2, \psi\}$, where ψ is the maximal angle on the left and on the right from where the light source could be still perceived. In that case the values of the fuzzy vector could be seen as degrees to which the light source is positioned more or lees close to the appropriate angular distance. For example, for values given above, the angular distance of the light source is $-\psi$ with degree 0.87, $-\psi/2$ with degree 1, and so on. If the signals is noisy, all membership values will be quite close. In that case, further processing is necessary and the fuzzy filtering have to be applied. It consists of making bigger differences between particular membership values by using fuzzy monadic operators. One example is operation α-concentration when membership values are raised on power α, where α is a number bigger then 1. Another example is contrast intensification where values smaller then 0.5 are calculated using equation $2*u_i^2$, and values bigger then 0.5 are calculated using equation $1-2*(1-u_i)^2$. This operation make bigger differences between extreme values. For our previous example operation concentration ($\alpha=4$) gives fuzzy vector [0.57 1 0.16 0.03 0] and operation contrast intensification [0.96 1 0.73 0.34 0.08]. In the first case the biggest value is filtered out from all other values, and in the second case first three values are filtered out. Vision signal is now in the form suitable for further application.

CONTROL APPLICATION OF FUZZY VISION TRANSDUCER

The fuzzy vision signal is suitable for direct application in control if the control procedure is based on the fuzzy control principles. The system layout is shown in Fig.3.

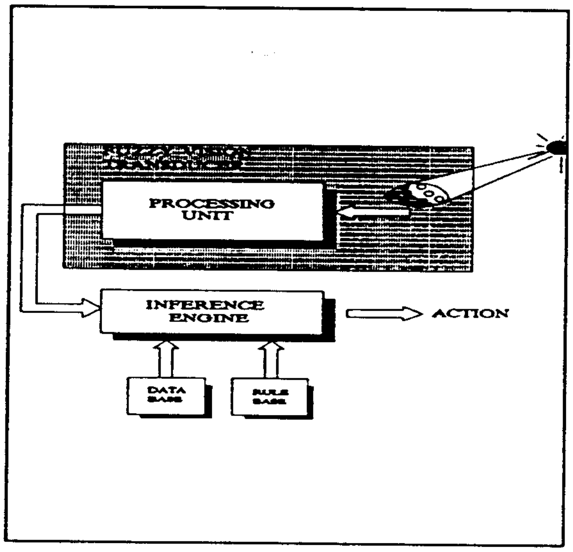

Fig.3. Fuzzy vision transducer based fuzzy control

The fuzzy vision signal (fuzzy vector or fuzzy matrix) is input to the inference engine. Like in all other fuzzy control systems there is a rule base with "if...then..." rules. One such rule could be "If the light is *left*, then the control is *positive*" where *left* and *positive* are verbal notations of fuzzy sets. Definitions of fuzzy sets (their membership functions) are given in data base. Fuzzy sets of light position and fuzzy vision signal have the same shape of membership function, because they are defined on the same support set. For example in the case discussed previously *left* and *right* must be five element fuzzy vector whose membership values are defined subjectively (but not arbitrary) by an expert. For example *left* could be defined as [1 0.6 0.3 0 0].

Now in inference engine the degree of fulfilment of each rule is calculated, fuzzy set of control is determined and a crisp control value obtained using appropriate interpretation method. This procedure will be illustrated with two control examples:
(1) position control based on principles of eye-hand coordination and
(2) tracking control for light source detection and following (something like an "artificial fly").
For the first case the system is schematically shown on Fig.4.

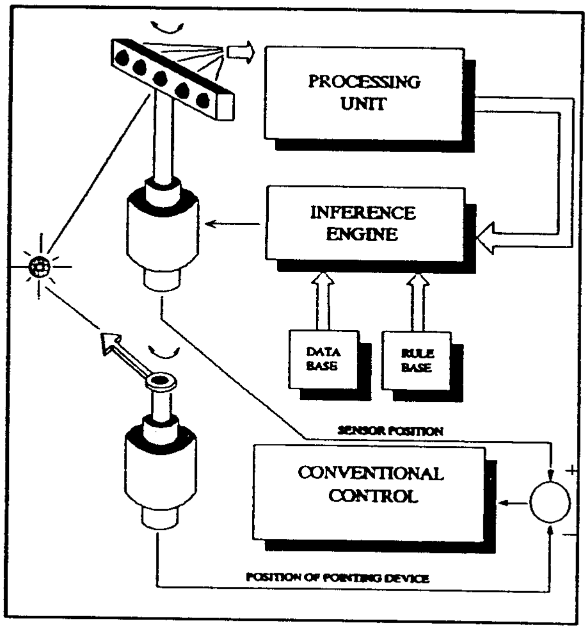

Fig. 4. Fuzzy position control based on eye-hand coordination

It consists of an eye (fuzzy vision transducer) and a hand (pointing device). The eye and the hand have independent motors, so each of them can rotate independently. When the light turns on anyway on the semicircle, the fuzzy vision transducer creates the fuzzy vision signal which carries information about the light angular position. This signal is used as an input to a fuzzy position control whose output is a voltage u_E applied to DC motor. This motor rotates the eye. The eye angle ψ_E is measured by an angular position sensor whose output is used as a reference input to a conventional feedback position control of the pointing device. The system was simulated using only three control rules:

(1) If the light is *left*, then u_E is *positive*.
(2) If the light is *central*, then u_E is *null*.
(3) If the light is *right*, then u_E is *negative*.

and max-min composition. The obtained results, described in [6], were quite satisfactory. The vision sensor stops rotating when its optical axis intersects the light. The pointing device starts to rotate at the same time as the vision sensor. For final adjustment of pointing device precise information of the vision sensor angular position was used.

Another example is tracking control system for light source detection and following, shown on Fig.5.

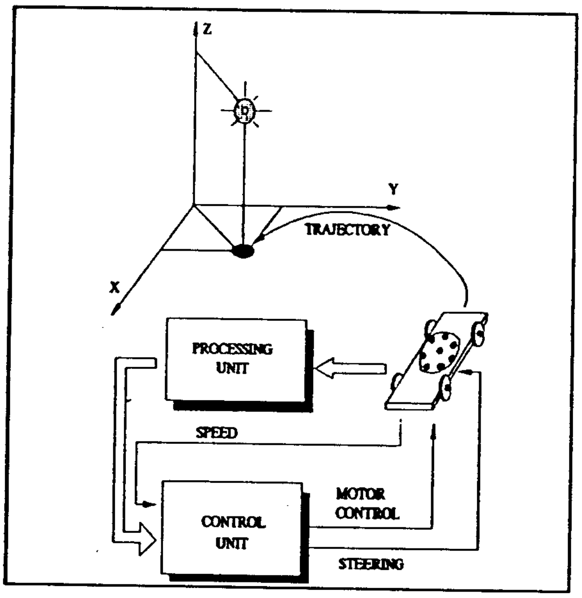

Fig.5. Fuzzy control system for light source detection and following

The system consists of the vehicle equipped with a two dimensional fuzzy vision transducer and the fuzzy control unit. Its task is to locate the point light source, and to drive the vehicle right behind the light. Fuzzy vision transducer creates a fuzzy vision signal in the form of fuzzy matrix. This fuzzy signal is then applied as an input to the control unit whose another input is the crisp value of the vehicle speed. Fuzzy control unit has two outputs: steering angle, and main motor control. Two sets of rules were used: simple steering rules (7 rules) and more complex motor control rules (28 rules).

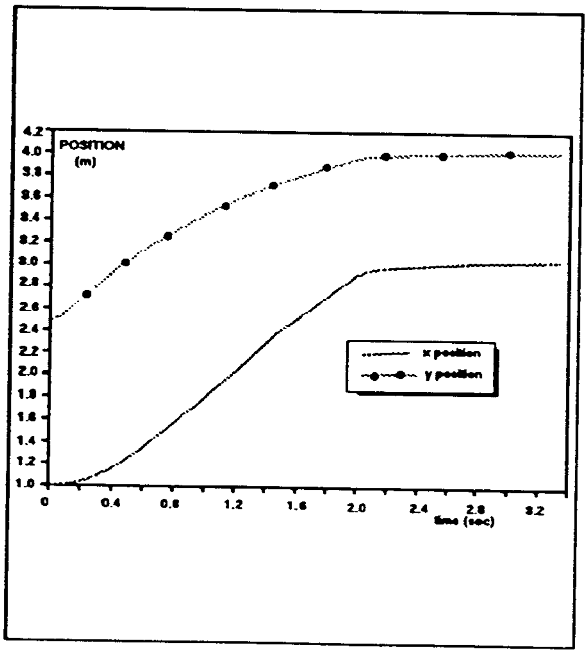

Fig 6. Time dependence of vehicle x and y trajectories

The system was simulated using realistic, nonlinear model of a small scale vehicle. The obtained results were also satisfactory. Typical time dependence of the vehicle x and y trajectories are shown on Fig. 6.

Starting (x,y) position of the vehicle was (1,2.5) and light was positioned 1 m behind point (3,4). As Fig.6. shows trajectories are quite smooth without overshoot.

CONCLUSION

As Nature is unlimited source of inspiration our inspiration for the simple vision sensor came from the Nature, too. The simple vision sensor called "fuzzy eye" was developed and conceived as an artificial apposition compound eye of insects. Although so primitive, it could be still successfully used in lot of vision based control tasks. Its application in control field needs additional processing of vision sensor information, so here we have proposed its improvement and construction of *fuzzy vision transducer*. It has two main parts. The first one is a fuzzy eye, and the second one is a processing unit, where sensor information are analyzed, reshaped and transformed into a signal suitable for further applications.

Two possible applications have been mentioned and illustrated by simulations: position control based on principles of eye-hand coordination and tracking control for light source detection and following.

Important is to emphasise that the same principles could be used for other kind of sensors, too. For example using thermal, sound, magnetic or chemical sensors, appropriate simple and effective sensing devices, capable for sensing heat, sound, magnetic field or smell could be constructed.

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