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# Fuzzy sensor for the perception of colour

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**Abstract** : The aim of this paper is to propose a new method for building a fuzzy partition on multi-dimensional spaces. This method is apply for creating fuzzy symbolic sensors which use multi-component measurements. Colour sensing is an interesting perception to apply this method. Indeed, men have good control on this sensing but can not explain it simply. Then, the fuzzy colour sensor can learn human perception of colour and does not need explicit information about colour perception mechanisms.

## 1 Introduction

Introduced since several years, *fuzzy symbolic sensors*, also called *fuzzy sensors*, are intelligent sensors which are able to receive, to produce and to handle fuzzy symbolic information [Foulloy 88], [Benoit 91]. This particularity allows them to be used as perceptive organs for symbolic controllers like fuzzy controllers and fuzzy expert systems. Furthermore, this kind of sensor can own the most advanced functionalities of intelligent sensors, like auto-adaptation and learning, by using artificial intelligence techniques as proposed by Zingales [Zingales 91].

Actual fuzzy sensors work on single-component measurements like distance, temperature and so one. In order to make fuzzy description of a multi-component measure like colour or smell, we propose an original fuzzy description method based on multi-dimensional fuzzy sets. In order to perform this method on a real sensor, we chose to build a fuzzy colour sensor which make the fuzzy description of the colour of a surface.

## 2 Fuzzy sensors

Fuzzy symbolic sensors are based on the translation of information from a numerical representation to a symbolic one. To perform a symbolic measurement, it is necessary to clearly specify the relation between symbols and numbers [Zadeh 71]. Introduce a set of symbols  $S$ . Let  $E$  be the set of all possible measurement values. An injective mapping from the symbolic set  $L$  in the set of the fuzzy subsets of measurements. This mapping called a *fuzzy meaning* and denoted  $\tau : S \rightarrow F(E)$  associates any symbol to a fuzzy subset of measurements. Symbolic measurement is now obtained from a mapping, called a *fuzzy description* and denoted  $\iota : E \rightarrow F(S)$ . It associates any measurement to a fuzzy subset of the symbolic set  $S$ . There is a fundamental relation between fuzzy description and fuzzy meaning. If a symbol belongs to the description of a measurement, then the measurement belongs to the meaning of the symbol, i.e:

$$\mu_{\iota(x)}(a) = \mu_{\tau(a)}(x) \quad (1)$$

If the set of the symbol meanings is a fuzzy partition of  $E$  then we have a fuzzy nominal scale [Benoit 93], which is an extension to fuzzy subsets of the concept of nominal scale [Finkelstein 84]. For fuzzy sensors, we always impose to be in this case .

In the following example, a fuzzy telemeter use the set of symbols  $S=\{Close, Medium, Far\}$ . We can see the fuzzy meaning of symbols and the fuzzy description of the measurement  $x=12$  cm.

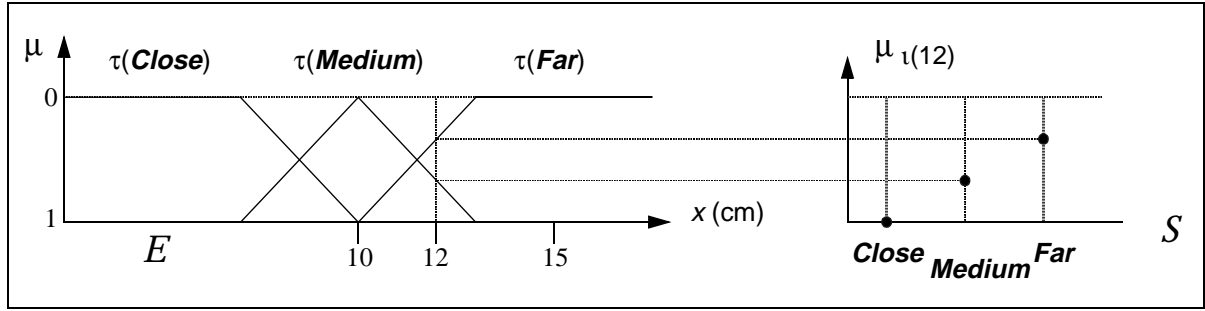


Fig. 1

### 3 Multi-component fuzzy sensors

When a sensor use several transducers, the measure is a vector of numerical values, and the measurement set is a multi-dimensional volume. Then, the meaning of each symbol must be a fuzzy set defined in this multi-dimensional volume. Furthermore the set of meanings has to be a fuzzy partition of the measurement set.

In this paper, we consider an initial knowledge about measurement. This knowledge is materialized by the meaning of symbols on a small subset  $V$  of the measurement set. Then the measurement set is partitioned in  $n$ -simplexes with the Delaunay triangulation method. A  $n$ -simplex in a  $n$ -dimensional space is a polyhedra with  $n+1$  vertices. For example, a 2-simplex is a triangle and a 3-simplex is a tetrahedron. The points used to perform the triangulation are the elements of the set  $V$ .

The membership function of the meaning of each symbol is defined on each  $n$ -simplex by a multi-linear interpolation. We suppose the restriction on a  $n$ -simplex of the membership function of the meaning of a symbol  $s$  is :

$$\mu_{\tau(s)}(v) = \mu_{\tau(s)}(x_1, x_2, \dots, x_n) = a_1x_1 + a_2x_2 + \dots + a_nx_n + a_{n+1} \quad (2)$$

The value of this function is known for the  $n+1$  vertices of the  $n$ -simplex. So the  $n+1$  factors  $a_i$  can be calculated.

$$A = M^{-1}B \quad M = \begin{bmatrix} x_{1_1} & \dots & x_{1_n} & 1 \\ \dots & \dots & \dots & \dots \\ x_{n+1_1} & \dots & x_{n+1_n} & 1 \end{bmatrix} \quad A = \begin{bmatrix} a_1 \\ \dots \\ a_{n+1} \end{bmatrix} \quad B = \begin{bmatrix} \mu_{\tau(s)}(v_1) \\ \mu_{\tau(s)}(v_2) \\ \dots \\ \mu_{\tau(s)}(v_{n+1}) \end{bmatrix}$$

Where  $v_i$  is the  $i^{\text{th}}$  vertex of the  $n$ -simplex, and  $x_{ij}$  is its  $j^{\text{th}}$  component.

This process is performed on each  $n$ -simplex and for each symbol. Then we have a fuzzy nominal scale defined on  $E$ . This scale is an extension of the fuzzy nominal scale on  $V$ .

With this method, the knowledge needed to configure the sensor is very compact. It can be acquired during a learning phase by a communication with a system called teacher which can be a man or an expert system. During the learning phase, the teacher and the sensor analyse the same phenomenon, and the teacher gives its description to the sensor. The sensor increases its knowledge with its measure associated to the teacher description. Then it can build the fuzzy nominal scale.

### 4 Colour measurement

Human beings perceive electromagnetic light beams by four types of photochemical transducers: three cones for day vision and one rod for night vision. The photometric sensors give back information in relation to the received energy. The sensation of colour is generated by the different spectral sensitivities of the cones. The “blue” cones detects short wavelength, whereas the “green” and “red” cones detect respectively medium and long wavelengths.

The artificial sensing (for example the video camera) is based on three photometric transducers that recreate the effects of red, green and blue cones. For the fuzzy colour sensor, we use three photo-transistors with optical filters. The sensor

has three components : a light source, a sensing unit, and a measurement head. The sensing unit includes the transducers, a signal conditioner, and a computation device which performs signal processing, fuzzy description, and learning procedure.

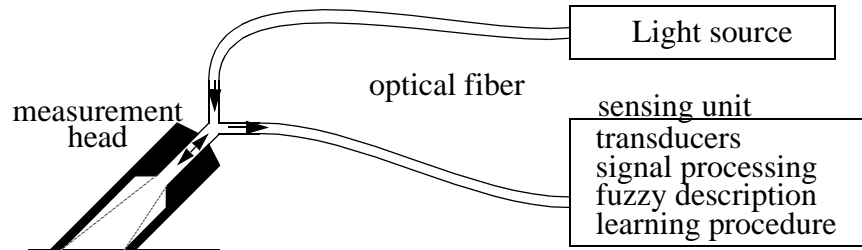


Fig. 2

#### 4.1) Fuzzy description of RGB components

The responses of the detectors are normalized between 0 and 1, and then the colour space is simply a unit cube (R,G,B). This colour space is used as the measurement set of the fuzzy sensor. For partitioning the whole measurement universe, the vertices of tetrahedron must be characteristic points. Then, the smallest partition contains eight elements, and the vertices of the cube are characteristic measurements. Experiments show that for several basis colours, the learning need several characteristic points (2 or 3) for a symbol. Contrary to men, it makes an important difference between pale and dark colours.

#### 4.2) Fuzzy description of chrominance

During a colour description in the common language, the luminosity is usually expressed separately. For example we can say “pale blue” or “dark red”. In order to introduce this knowledge in the sensor, a non linear transform is applied on the RGB cube (see fig. below). Then, luminance and chrominance can be describe separately. The measurement set of the luminance is monodimensional, and its description is not developed in the paper. The measurement set of the chrominance is two-dimensional, it is called the chrominance plane of colour and it is used as the measurement set. The experiments confirm the advantage of this representation : the sensor generally needs only one learning point by symbol.

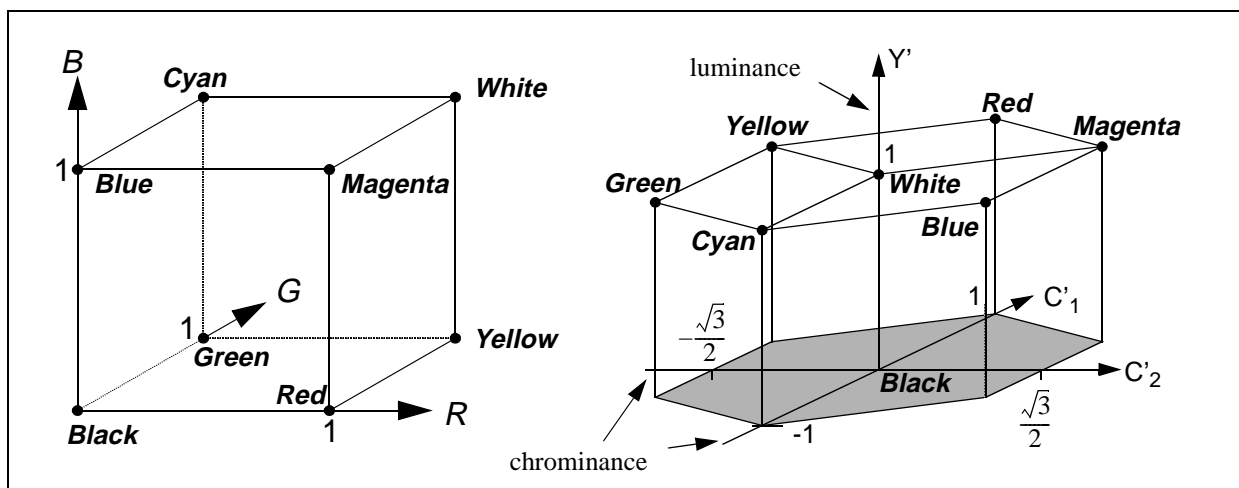


Fig. 3 RGB cube before and after the transform

## 5 Conclusion

Multi-component fuzzy sensors can be use in many domains where the measurement use several basis measures. They

are especially adapted for sensing with unknown mechanisms, but easily controlled by a man. Indeed, the sensor does not need explicit information about these mechanisms to be configured.

As the fuzzy colour sensor gives a fuzzy representation of the measure, it can be used in a symbolic control system. The method applied to build multi-dimensional fuzzy sets can be used in many applications. For example, pattern recognition needs to make a classification in a multi-dimensional space, and will be an interesting domain to develop this method.

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