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Takagi, Hideyuki
Computer Science Division, University of California, Berkeley

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Survey: Fuzzy Logic Applications to Image Processing Equipment

Hideyuki TAKAGI*

Computer Science Division, University of California, Berkeley, CA 94720 USA
TEL (510)642-8015, FAX (510)642-5775, takagi@cs.berkeley.edu

Abstract

In this paper, we describe some applications of fuzzy logic to the design of image processing equipment, and how fuzzy technology is used in this area. Most of this equipment is available on the market. The equipment described here includes mechanisms for autofocus, auto-exposure, auto-zooming, and automatic white balancing for cameras and video camcorders; image stabilization for camcorders; electrophotographic controls in copying machines; television image quality control; image codec systems; and stepper alignment for semiconductor device processes.

1 Introduction

Expectations of applications of fuzzy logic arose nearly two decades after its birth. The theory was realized as a practical technology and came into widespread use five years after this. Japan has been the center of such applications, from the practical point of view. In Japan, fuzzy logic control has been applied in industry through the 1980's. These applications were reported and demonstrated in the 2nd IFSA Congress in Tokyo in 1987, thereby sparking further interest in the field. One famous example is the Sendai subway system, which is efficiently controlled by fuzzy rules.

Since then, many electronics companies have started applying and incorporating fuzzy logic into their consumer products. Some of these were temperature control of showers (1988), air-conditioner control, and auto-exposure system for camcorders (1989). 1990 was the year in which fuzzy logic burst into the market dramatically, when the first washing machine explicitly carrying the word "fuzzy" entered the market. Consumers in Japan accepted the word "fuzzy" as a technical one (since it has meaning only in English), and it came to signify new AI there. Of course, the use of the term cannot boost sales alone. When the washing machine first arrived on the market, it used fuzzy logic in conjunction with more sensors to determine dirt quantity, type of the dirt etc. and automatically decided washing time. Therefore the impression of a clever machine was conveyed to the consumer. Since this product had an extremely high sales record, many other consumer companies started similar applications.

After this boom, many researchers and engineers entered the field of fuzzy technology, and there was development in the technical and application aspects. On the technical side, automatic designing of fuzzy systems was developed rapidly. Many methods were proposed for this, using neural networks, gradient methods, genetic algorithms, and meta-rules, some of which were applied in practical product development. The next phase of application-oriented research involves learning equipment which can adapt itself to a particular user. In consumer appliances, the uses of fuzzy logic have expanded to include image processing equipment such as cameras, TVs etc. This paper is a survey that introduces such applications.

Although many applications are referred to as fuzzy logic control, fuzzy logic does not directly do the controlling in consumer appliances. Fuzzy inference determines the important parameters, which are then used by a conventional controller. This is also true of the specific applications that are discussed in subsequent sections here. The significant point is that fuzzy logic can model and emulate human decision making, which is outside the purview of conventional control theory.

2 Cameras

2.1 Canon: Auto-focus

Canon Inc. has applied fuzzy logic to decide on which object is to be focussed on, in the field of view, and then control the auto-focus mechanism to focus on that object [1]. Earlier, cameras used the object centered in the field of view as the desired focus. This sometimes led to error, as in the case of two objects present off-center. This problem had to be solved by the photographer by first focusing on one object, locking the auto-focus, and then reorienting the camera to get the desired shot. This process was a troublesome, manual one. To circumvent this, fuzzy reasoning has been introduced to guide the auto-focus mechanism.

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*The author is a Visiting Industrial Fellow at the University of California at Berkeley and a Senior Researcher for Central Research Laboratories, Matsushita Electric Industrial Co., Ltd.

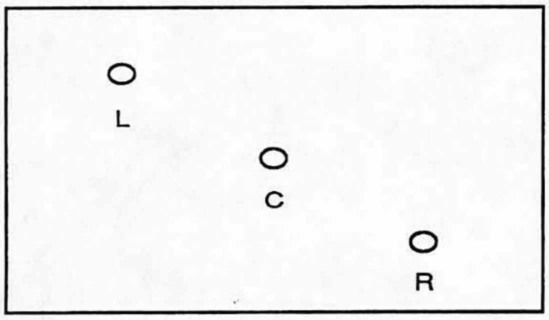


Figure 1: Three points to which distance is measured

First, distances to three points in the field of view (shown in Figure 1) are measured. Using this data, and the relationships between them, fuzzy logic decides where the desired focus lies, and then focuses on that point. Fuzzy rules used to do this were obtained by an analysis of about 300 pictures taken by 8 persons. Table 1 shows the rules used in the experimental simulations during development of the product. The final product may have more rules [2].

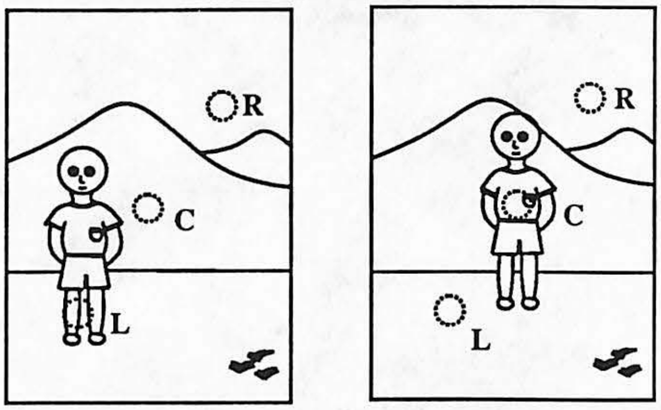
#1: IF C is *near*, THEN P_c is *high*
#2: IF L is *near*, THEN P_l is *high*
#3: IF R is *near*, THEN P_r is *high*
#4: IF L is *far* and C is *medium* and R is *near*, THEN P_c is *very_high*
#5: IF R is *far* and C is *medium* and L is *near*, THEN P_c is *very_high*

Table 1: Fuzzy rules for the Canon autofocus system; L, C, and R denote measured to the three points shown in Figure 1. P_l, P_c, and P_r denote plausibility of finding the object of focus there.

Comparing Figure 2(a) and 2(b), we see that Figure 2(a) has the main subject on the left, whereas Figure 2(b) has the main subject at the center. However, the relationship is L<C<R in both cases, and both satisfy Rules 2 and 5. In this case, the decision depends on the values of L,C and R, and this comparison is done with the help of membership functions. It is very hard for binary logic rules to model this situation, and a large number of rules may be required. A few fuzzy rules, however, can easily deal with this problem.

The performance of this method has been evaluated by using 288 pictures taken by 8 persons. The fraction of correctly focussed pictures, for both with and without the fuzzy rules, is shown in Table 2. We see that there is an increase of 22.9% in the focusing rate.

The camera incorporating this was put on the market in 1989. The inference is realized on a 4-bit microcontroller with a 500-byte memory.



(a) (b)

Figure 2: Example of scenes

method	focusing rate
three measured distances + fuzzy inference	96.5%
distance to the center	73.6%

Table 2: Performance of auto-focus method

2.2 Minolta: Auto-Focus, Auto-Exposure, and Auto-Zoom

Minolta Camera Co., Ltd. has used fuzzy logic to realize the three mechanisms of focusing, zooming and deciding exposure automatically.

To implement auto-focusing, it is necessary to find where the main subject is. The fuzzy reasoning system for doing this uses six distance distributions, which are obtained by preprocessing the outputs of four auto-focus sensors, lens information, and one sensor which detects camera position. Seven fuzzy rules, obtained from the analysis of about a thousand pictures, determines the location of the main subject to focus on. These sensors were the same as those present in earlier models. Adding the fuzzy logic for decision-making led to an improvement of 15% in the focus hit rate.

To implement auto-exposure, fuzzy reasoning is used to determine exposure value, and the best combination of shutter speed and aperture, depending on the type of scene being photographed.

The exposure value is determined by three fuzzy inference modules, by using brightness values obtained from 14 zones in the field of view, and the position of the main subject (which is determined by the autofocus mechanism described above). The first fuzzy system uses the difference in brightness between the main subject and the background to output a measure of the amount of backlighting present. The second fuzzy system decides whether the exposure is to be focussed on only the main subject or the entire scene. The third system uses the outputs of these two fuzzy modules, and weights three measures of exposures (an average, at the center, and at the main subject), and then outputs the final exposure value.

The optimal combination of shutter speed and aperture is determined by fuzzy inference using the type of scene and the lens being used. The types of scene (for example, snap, portrait, close-up or natural scenery) is determined by the distance to the main subject, focus distance, lens magnification, lowest allowable shutter speed, exposure value et cetera. In a portrait photo, the focus is solely on the subject. In a scenery shot, the focus distance is at a large value. All such detail and fine control can be automated using fuzzy logic.

To implement auto-zooming, fuzzy reasoning needs to decide the speed of zooming the lens. When the main subject moves, the size of its image is held at a constant value, by zooming appropriately to compensate for the movement. If the zooming is controlled by merely using the distance to the subject, the error in this value leads to hatching at the correct distance. When the distance information is smoothed, hatching can be prevented, but quick zooming cannot be realized. Fuzzy reasoning decides on the zooming speed by looking at the ratio of current lens magnification to that one unit time ago, and its rate of change. The rules change the speed of the lens depending on how the object moves.

3 Camcorders

3.1 Sanyo: autofocus, auto-exposure, and auto-white-balancing

Sanyo Electric Co. Ltd. introduced fuzzy logic into some components of the camcorder [4]: auto-exposure (1989), autofocus (1990), and auto-white-balancing (1991). The brightness signal and color-difference signal obtained from the video signal (via a CCD), are filtered and then integrated to give a set of 8×8 values as shown in Figure 3. These are the inputs used to realize the automation referred to above.

Autofocussing is based on the observation that the high frequency components of the signal increase as the focus comes close to its optimum value. This is easy to do if the area from which the high-frequency component is obtained is small, but if the scene consists of moving objects, then focusing based on this idea becomes unstable. A stable focus, on the other hand, will be suboptimal in cases of motion in the scene. To solve this problem, a fuzzy system using eight signals is used: the high-frequency components passed through two different bandpass filters, brightness signal at the center of Figure 3 (areas $1 + 2$), zooming information, aperture information etc. The system has 21 fuzzy rules and decides the area to focus on and also decides on the direction to focus on, in case the object is not in focus. An example of such a rule is *IF brightness difference in center area is BIG and zooming is CLOSE to telephoto THEN* $y = 0.8$, where y is the degree to which the central area contributes in determining the focus.

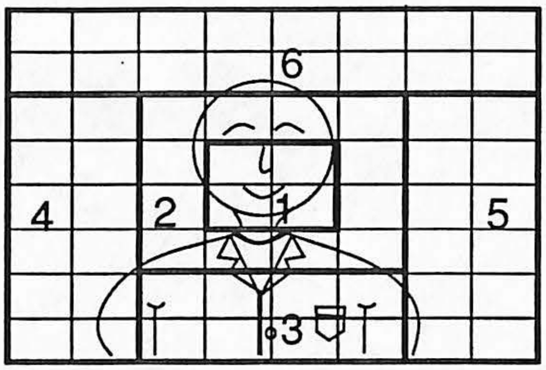


Figure 3: The six partitions of image plane

The autoexposure system decides on the exposure value by taking into account brightness signals from six zones in the field of view (denoted by v_i, $1 \leq i \leq 6$) and assigning them different weights. This handles the problem of excessive lighting from the front or the back. Since the video camera deals with motion, this exposure value must be continuously changed. This feature makes the situation significantly different from a still camera. As the scene or the camera keeps moving, fuzzy rules keep matching the situation to different degrees. Since this degree is a real number, the changes in output are smooth responses. In contrast, crisp rules would match completely or not at all, and only one rule would be applicable at one time. This involves discontinuous shifts in the exposure value. The fuzzy rules are eleven in number, and the j-th rule produces the a linear combination of the brightness values denoted by

$$E_j = w_{j1}v_1 + w_{j2}v_2 + \cdots + w_{j6}v_6$$

where w_{ji} is the weight given to the brightness value in area i. Each rule has a different set of weights. For instance, in cases of strong lighting, the rule may be: *IF maximum value of v_i is BIG, and average brightness is LOW, THEN those v_i which are smaller than the average are given BIG weights.* So this rule emphasizes the importance of darker areas. The final value of the fuzzy system is a weighted combination of the v_i.

The process of white-balancing is that of setting up a color reference by demonstrating the color white. This ensures that the recorded colors correspond to human visual senses. Usually this is done manually by showing the camera reference white patches. Auto-white-balancing has to arrive at the reference automatically. One way to do this is to assume that the image

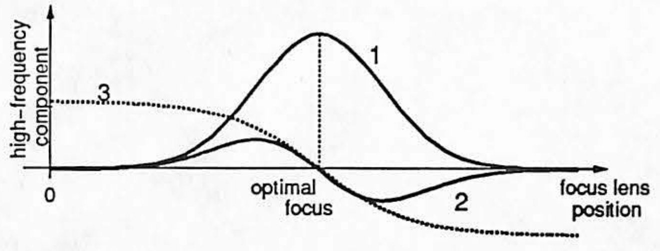


Figure 4: Characteristics vs. focus lens position: (1) high frequency component, (2) derivative of (1), (3) optimal speed of auto-focus motor

contains many colors and to average these out to arrive at what the white color should look like. This causes error because of large patches of specific colors. To solve this problem, the image is divided into 8x8 parts, and the color difference signal (R-Y, B-Y) is averaged after weighting each of these 64 areas differently. Then large areas of one color or strong brightness are detected and given less weight. Then 9 fuzzy rules use 8 inputs (such as color phase information, high frequency component from the autofocus system, position of the main subject, zooming information etc.) to output the reliability of the average color temperature computed in the previous step. For example, a rule might be: *IF high-frequency-component is STRONG and the lens is wide-angle and the main subject is at a LARGE distance, THEN reliability is HIGH.* The three fuzzy systems which we have described are not implemented as table lookup, but inference is done in software running on an 8-bit microcontroller. The program size is about 1 KB. All three fuzzy systems use the max-min method for inference. The autofocus and auto-white-balancing systems use constants for rule consequents whereas the auto-exposure system uses linear functions of its inputs in the consequent part (in the sense of Takagi-Sugeno-Kang model).

3.2 Canon: Autofocus System for Camcorders

Canon Inc. applied fuzzy logic for controlling the speed of the autofocus motor [5]. Their focusing principle is the same as that mentioned in Section 3.1, namely, that high frequency components are strongest when the image is in sharp focus. To find the correct position quickly, the motor must work at a high speed when the high frequency components are weak (picture is blurred), but must slow down as the correct position is approached.

The problem of controlling this motor is that the control depends on both the main subject and the type of scene. For example, when the main subject is low contrast, the motor overshoots, whereas excessive brightness causes the motor to slow down prohibitively. Conventional autofocus motors are controlled by using absolute frequency thresholds, as shown in Figure 4

To solve this problem, Canon used the frequency values as well as their rate of change as inputs to a fuzzy system using at least 10 rules, and regulated the motor speed. An example of such a rule is: *IF high-frequency-component is WEAK, and the differential rate is SMALL, THEN motor speed is HIGH.* The fuzzy inference used max-min-gravity method, with a simplified approximation for defuzzification. One cycle of inference takes at most 5 ms, and the program size is about 1.7 KB. The focusing time was reduced by 20% by this fuzzy technique.

3.3 Matsushita Electric: Image Stabilization for Camcorders

Matsushita Electric Industrial Co., Ltd. has applied fuzzy logic to determine whether movement of the image is due to shaking of the hand or the object being photographed [6]. This camera was put on the market in 1990.

As consumer camcorders become lighter and more portable, the problem of dealing with hand-shaking has worsened and needs to be solved. Shooting a movie while walking or from a moving vehicle exacerbates the problem. To tackle this, a customized LSI chip detects the motion vector, and a fuzzy system decides if the motion is due to hand-shaking. Digital signal processing is used to compensate if this is indeed the case. There are two ways to detect jitter due to handshaking. One uses vibration sensors, while the other does pure signal processing only. This system uses the latter method.

The inputs to the fuzzy system are four motion vectors, each coming from one of the four regions into which the image has been divided (see Figure 5), and their rates of change. Each of these four regions is further divided into 30 smaller areas. Two successive frames are compared to compute the spatial difference values for each area. These differences are summed over the 30 areas in a region to produce a net difference R_i for region i. For each region, some one shift vector results in the smallest value of R_i. This minimizing shift is the motion vector v_i for that region.

Fuzzy reasoning uses the values v_i as inputs to detect shaking of the hand. When this is the case, and there is no moving object, then the minimum R_i is almost zero. If there is a small moving object in the image and the hand is steady, then the area corresponding to the moving object has a spatial difference value that is different from the surrounding areas. However, the net R_i values are small. When there is both hand motion as well as object motion, then the minimum R_i is bigger than in the no-moving-object case.

The time derivatives of the R_i values are also used by the fuzzy system. This incorporates information about the size and motion of the moving object. A rule using these may be: *IF the four motion vectors are almost parallel, and their time differential is SMALL, THEN shaking of the hand is occurring and the direction of the shaking is the direction of the moving*

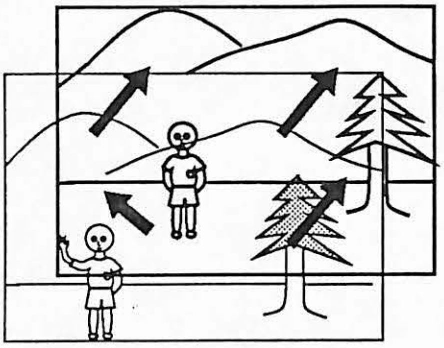


Figure 5: Example of motion vector

vectors.

Once the direction of shaking is known, the frame in the buffer is shifted in the opposite direction to this motion, so that stabilization is achieved. This image processing became possible only because all signals used are digitized [7].

4 Photocopying machines

4.1 Canon: Electrophotography process

Canon Inc. used fuzzy technology in the electrophotography process of a machine put on the market in October 1990. This process is a delicate one and is influenced by temperature, humidity, toner condition, and the ratio of black to white on the original page etc. In conventional machines, this is manually managed according to the environment of the machine. The new product by Canon automated this by using a temperature sensor and a potentiometer which picked up the black/white ratio from the charge distribution on the drum. The fuzzy system used these two inputs and controls the charger so that the drum is given just the right amount of charge [8]. Each of these inputs can attain the values high, medium, and low.

The fundamental process of a copy machine controls the charge imparted to the drum in several steps (shown in Figure 6): (1) charge the photoconductor drum uniformly, (2) erase the charge corresponding to the white areas by scanning, (3) attach toner to the charged areas of the drum which correspond to the black portions, (4) decrease the potential of the surface, (5) transfer the toner to the copy paper by static electricity, (6) remove the copy paper, (7) fix the toner to the paper thermally. Steps (4), (5), and (6) are controlled by fuzzy logic.

For step (5), nine rules are used to produce the control value of the charge using three labels each for the two inputs, and three labels in the consequents. They are shown in Table 3. One such rule is : *IF temperature is HIGH and black/white ratio is LOW, THEN charge value is HIGH.*

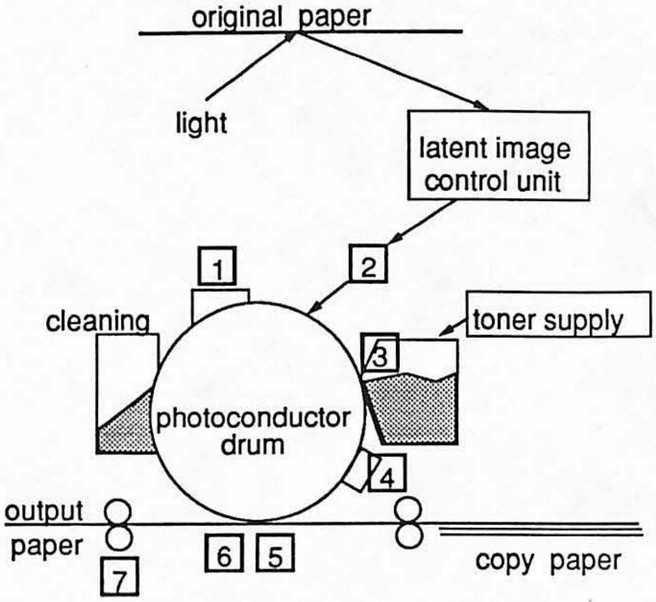


Figure 6: Diagram of electrophotography process: (1) charging the dram uniformly, (2) erasing the charge corresponding to the white areas, (3) attaching toner, (4) decreasing the potential of the drum, (5) transferring toner to the copy paper, (6) removing the copy, (7) fixing the toner to the paper

The inference method is max-min-gravity and uses a Mamdani-type fuzzy controller. The resulting system can adjust to a changing environment, eliminates the need for manual adjustment by maintenance personnel, reduces the number of paper jams, and maintains a stable quality of the copies.

		black/white ratio		
		low	mid	high
temperature	low	low	low	mid
	mid	mid	mid	high
	high	high	high	high

Table 3: Fuzzy inference rules that decide charge value in the process of transferring toner to copy paper

4.2 Ricoh: Electrophotography Process

Ricoh Co., Ltd. applies neural networks and fuzzy logic to this process to hold the quality of the image constant, even if the environment changes during the copying [9]. Fuzzy logic controls the toner supply (position 3 in Figure 6), whereas the neural networks provides correction in latent image control unit (position 2 in Figure 6) when the environment fluctuates.

In order for the neural net to do its job, it must be trained in different environments. For this, three different temperatures and three values of humidity were used, and one of five charging grid voltages and exposure voltage were supplied as corresponding output. The trained net accepts environmental conditions, fatigue parameters, and the uncorrected voltages, and outputs the corrected voltage values to be fed to the drum. Conventional control resulted in jumps in these voltages by as much as 50-60 volts, whereas with the net, this has been reduced to 10 volts.

Fuzzy control realizes a stable image quality by controlling toner supply. Depending on toner usage, the ratio of developer to toner keeps changing, and this may cause nonuniform contrast over the copy. The process also has a time delay since a buffer is used for the toner delivery, and the response to any change in the supply is delayed because of the buffered quantity. Furthermore, it is sensitive to temperature and humidity. The fuzzy reasoning system developed to solve this problem uses the black/white ratio and its time differential as its inputs and regulates the toner supply. An example of the fuzzy rule here is : *IF contrast is OK and it is increasing, THEN stop toner supply quickly: IF contrast is light and it is steady, THEN supply more toner.*

The reasoning method used is max-min-gravity. For both analog and digital copying methods, this fuzzy system reduced the variation of image contrast to between 11% and 90% of that of conventional methods.

4.3 Sanyo: Toner Supply Control

Sanyo Electric Co., Ltd. has applied fuzzy logic to the toner supply controller (position 3 in Figure 6) to preserve high image quality [10].

A magnetic sensor measures the ratio of toner to carrier (iron filings, etc.) at the position marked 3 in Figure 6, and more toner is supplied when the toner density becomes less than a certain level. Conventional control always supplies a constant amount of toner, and this does not depend on the white/black ratio in the original image (this is related to the quantity of toner usage). This leads to unstable copy density which changes over time.

Sanyo has introduced a fuzzy controller which monitors not only toner density but also its time derivative, and changes the amount of toner supply accordingly. The main ideas used in the rules are :

(1) IF toner density is LOW (HIGH), THEN supply greater (lesser) amount of toner,

(2) IF toner density DECREASES, THEN supply greater amount of toner,

(3) IF toner density INCREASES, THEN supply greater amount of toner.

Toner density increases just after the toner is supplied. However, if a large part of the original image is black, toner density begins to decrease soon. Rule (3) attempts to guard against this situation. The actual rules are shown in Table 4.

Several output membership functions are used for the target toner density to realize precise control at this position. The inference method is max-min-gravity and uses a Mamdani-type fuzzy controller. Use of the fuzzy system reduced the variation of toner density to 0.94% from 1.53% for conventional methods. It also reduced the standard deviation in the image density of a half-tone copy from 0.0617 for conventional control to 0.0432 (this corresponds to a 30% improvement in the stability of the image quality).

		time derivative of toner density						
		NL	NM	NS	ZR	PS	PM	PL
toner density	NL	PL		PL	PM		PM	
	NS		PL		PS	ZR		PL
	ZR	PL		ZR	NS		NM	
	PS	PM		NM		NL		PS
	PL	NL						

Table 4: Fuzzy inference rules for image quality control of toner supply; N: negative, P: positive, S: small, M: medium, L: large, and ZR: zero

4.4 Sanyo: Color Copying

Sanyo Electric Co., Ltd. are considering using fuzzy sets to define certain natural colors correctly so that copy machine colors can be compared to this reference, and the color temperature be adjusted in case of deviation [11]. Human subjective tests are used to set up the reference colors.

5 Television equipment

5.1 Sanyo: Television Sets

Sanyo Electric Co., Ltd. used fuzzy inference for controlling the image quality of a TV reception set, which appeared on the market in autumn 1990. The fuzzy system controlled the contrast, brightness, velocity modulation and sharpness. The input parameters are the ambient brightness in the room and the distance of the viewer from the set [12]. One basic principle used here to construct the fuzzy rules can be expressed as: When the room is brightly lit, and the viewer is far away, then the region boundaries on the picture should be sharper and clearer, whereas if the viewer is close and in a darkened room, then the sharpness should be less as the high-frequency components are accompanied by noise. See Table 5 for some of the other principles used.

The actual rules in the system are more detailed for finer control. There are four membership functions for brightness, three for distance, and seven for the output variables. The study implies that different sets of rules apply to ordinary TV programs as opposed to movies. The inference is by the max-

	room		from TV to viewer		
	bright	dark	far	mid	near
contrast	big	small	big	mid	small
brightness	big	small	same		
velocity modulation	big	small	big	mid	small
sharpness	big	small	same		

Table 5: Fuzzy inference rules for image quality control of TV set

min-gravity method and is implemented by a look-up table in the final product. The table has 8 × 3 × 2 cells, from the two inputs and the two modes, each cell containing a value for each of the four outputs.

Room brightness is computed from a light sensor to give one of eight values. Viewer distance is computed by locating the remote control, and has three possible values. The microcontroller uses these to consult the look-up table, and four output values are received. This process is repeated every 50 ms.

5.2 Others

Mitsubishi Electric Corp. has put similar products on the market. Contrast and sharpness are controlled using brightness and viewer distance [13]. The implementation of the fuzzy system is by table look-up. Furthermore, in case of satellite broadcasts, frequency characteristics for noise reduction and sharpness are controlled by fuzzy logic according to incoming signal power. For example, rain may reduce the signal-to-noise ratio, but noise can be reduced by suppressing high frequency components.

Sony Corporation marketed a TV set in autumn 1989, in which image quality was continuously adjusted. Now, there is a product called AI-Television which uses fuzzy logic. Although the details of the fuzzy reasoning are not available, the inputs are brightness signal, color signal, beam current, and noise level. The system controls contrast, brightness, color, sharpness, and noise reduction etc. [14].

6 Codecs

In April 1991, Mitsubishi Electric Corp. introduced fuzzy inference into the video codecs used by their video-conferencing system. Video-conferencing equipment enables various people to communicate via TV sets and cameras using high-speed bidirectional phone lines.

The coding essentially uses data compression techniques depending on the extent of change in the picture. For instance, rapid change in the picture leads to finer quantization, and vice versa. According to their news release [15], the system compares successive frames to compute the changes The fuzzy controller's inputs are the amounts of such changes now (x_0), in the recent past (x_1), in the far past (x_3), and at some point inbetween (x_2). The output controls the quantization process.

An example of a rule is: *IF x_3 is almost the same as, but x_0, x_1, and x_2 are below a threshold determined by the current quantization rate, THEN reduce the quantization rate.* The motion-tracking ability of the system increased by 30 to 50 percent as a result of using the fuzzy system.

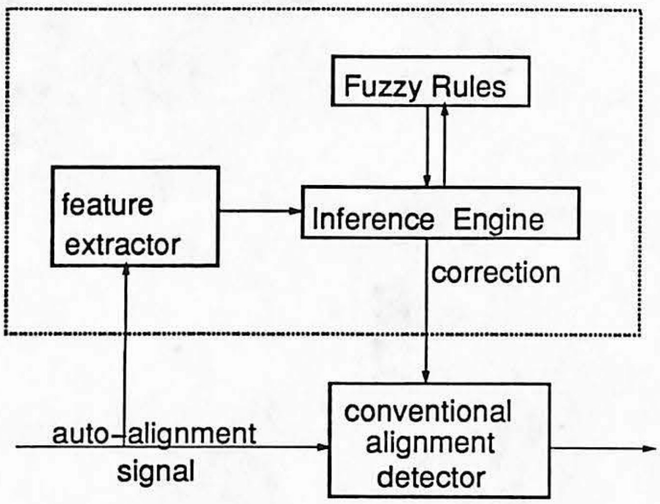


Figure 7: Fuzzy alignment correction system

7 Stepper alignment in semiconductor manufacturing

Canon Inc. has used fuzzy logic in the task of aligning semiconductor wafers in the process of producing chips [16].

In semiconductor device manufacturing, it is required to locate and align the wafer on the assembly-line very precisely. This has become increasingly important as the chip complexity and density increases. Each wafer is equipped with an alignment mark for this purpose, which is read automatically as a reference. However, since many different companies manufacture wafers, there is variation as to the structure and position of the alignment mark. So the alignment process must have the knowledge required to correct for this variation. Canon developed the system that corrects alignment error of conventional alignment position detector and is shown in Figure 7. Fuzzy logic is used for encoding and using the knowledge in the system.

The alignment mark is a sharp depression in the wafer surface. The aligning equipment uses the diffraction or reflection of a laser beam from the two edges of the mark to locate it. The peak location of this synthesized returning laser signal is fed into one fuzzy system, which outputs the correction to be applied to locate the mark. The alignment error between the position

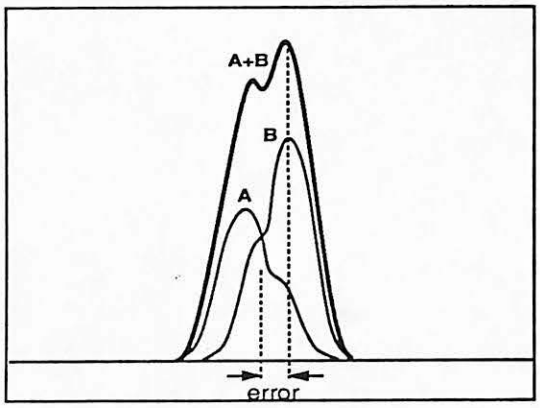


Figure 8: fig:Correcting the alignment error

of the peak and real position is shown in Figure 8. The human knowledge involved deals with the structure and shot position of the mark separately. Therefore, two rulebases are used to deal with the problem.

The first rulebase relates the position of the peak (see Figure 8) to the actual center of the mark. Another rulebase stores the relationship between alignment shot position on the wafer and position of the mark. These two rulebases together determine where precisely the mark is. These relationships have been observed empirically, and the rules are constructed from data that has been experimentally obtained.

The fuzzy rules were designed by analyzing 84 cases. The ensuing performance had an average error of zero, and the standard deviation was reduced by half.

8 Conclusion

Fuzzy logic has already been widely applied to consumer home appliances. Now there are two major trends in the application of fuzzy techniques to consumer electric/electronic appliances. One trend is to have learning ability in the equipment so that it can adapt itself to the user's environment and preferences [17]. Initial approaches did this by fusing neural networks and fuzzy logic. Now the emphasis is on doing this and preserving safety. The other trend is applications to signal processing. Here, logic is used for decision-making and controlling parameters and quality. The fuzzy logic applications to image processing equipment described here comprise the initial stage of research in this direction.

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