Image-based Flame Control of a Premixed Gas Burner using Fuzzy Logics

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Abstract.

This paper presents an application of fuzzy logics for controlling the combustion flame of a premixed gas burner. The control objective is to achieve a good characteristic of combustion flame by visualizing the colors of the flame while maintaining its size as desired. The fuzzy logic controller adjusts the flow rates of gas and air independently through two stepper-driven needle valves. A CCD camera with an image-processing/frame-grabber card is utilized as a sensor unit. The image captured by the CCD camera is processed in real time to extract the color and size information of the flame. This information is then used as a feedback signal for the controller. The study results show that the fuzzy logic controller is able to automatically regulate the flame to achieve the objective as desired.

1. Introduction

In recent year, there has been a growing interest in image-based analysis and feedback control applied to engineering problems. Visual servo control of robotic manipulators is a well-known example. There is also a number of research publications indicating good potential applications of this image-based analysis and control in combustion processes. The references [1-2] provide excellent overviews of this subject. Iion et al. [3] conducted experiments using image processing techniques to study dynamics behavior of flames and timewise variation of high-luminous region in flames. One of their results indicated that the apparent flow velocity of the high-luminous region is approximately constant and is independent of the fuel velocity. Tao and Burkhardt [4] and Oest and Burkhardt [5] presented implementations of a vision-guided flame control system using a fuzzy logic plus neural network technique and an iterative minimization method, respectively. The experimental results of both works showed that the designed controllers performed satisfactorily.

This paper presents an experimental study of utilizing fuzzy logics as an image feedback controller for regulating the combustion flame of a premixed gas burner. The control objective is to achieve a good characteristic of combustion flame by visualizing the colors of the flame while maintaining its size as desired.

2. Experimental System

As shown in Figure 1, the experimental system employed in this work comprises (1) a premixed gas burner (2) a pc-computer with an image-processing/frame grabber card, (3) a camera, and (4) two stepper-driven needle valves for adjusting the flow rates of gas and air. The burner used here is known as a Meker burner, which is very similar to the well-known Bunsen burner. In operating the burner is installed in a chamber as shown in Figure 2. The

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main processor of the image-processing/frame grabber card is TMS320C81-MVP (Multimedia Video Processor) which consists of four DSPs (Digital Signal Processors) running in parallel. The camera is a CCD (Charge Coupled Device) mono camera. The gas used as the fuel is liquid petroleum gas (LPG). The air comes directly from an air compressor.

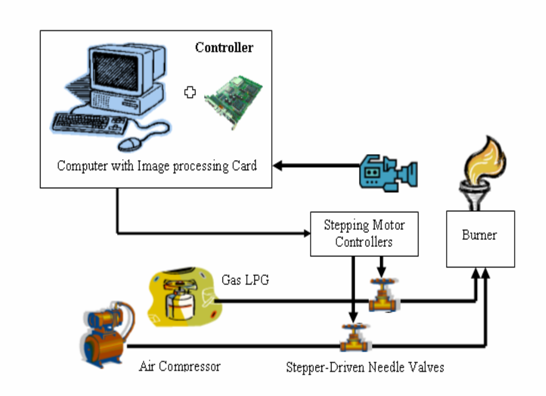


Figure 1 Experimental System.

Figure 2 Burner in operating.

3. Flame Analysis

In this paper we assume that the structure of the combustion flame consisting of two portions: blue and orange portions (see Figure 3). Moreover, flame analysis is based only on the colors of the flame. Three main color components detected by the camera are black, orange, and blue. The black color is the color of the background while the orange and blue colors are of the flame. These two last colors that we are interested are related to the performance of the combustion process. In general a good combustion flame should have solely the blue. The orange dues to soot and indicates that the combustion process is lacking of air.

In this paper the images captured by the CCD camera is gray. Each pixel of the images then can be represented by an 8-bit word that has the value between 0 and 255. Here, we process the image to extract the amount of the blue and orange by two threshold processes and one XOR operation. An example of the processed results is shown in Figure 4. Note that the numbers of white pixel of the bottom left and right pictures, which are 27.5 and 9.5, indicated the size of the orange and blue portions, respectively. These numbers are not the actual numbers of the white pixels, but they are some kind of the index that is equivalent to the size.

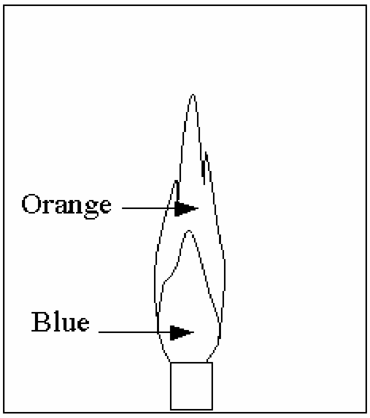


Figure 3 Combustion flame structure

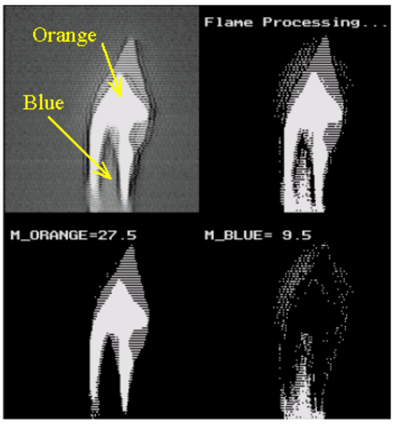


Figure 4 Processed Images.

4. Fuzzy Logic Controller

In this paper the control system consists of two fuzzy logics acting as a nonlinear controller. As shown in Figure 5, the first fuzzy logic controls the flow rate of the air while the other controls the flow rate of the gas. The two inputs for both fuzzy logics are identical which are the size errors of the orange and the blue portions of the flame. Note that the sizes are obtained in real time from the image processing processes as mentioned before. Here, the desired size of the orange is set to zero since we want to minimize this portion.

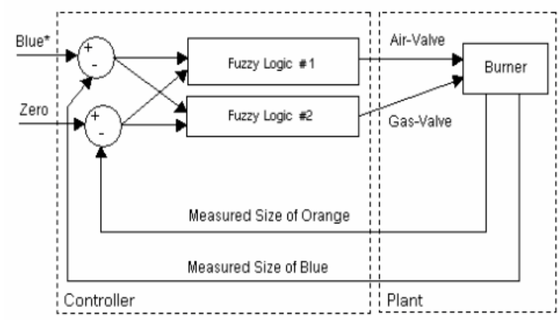
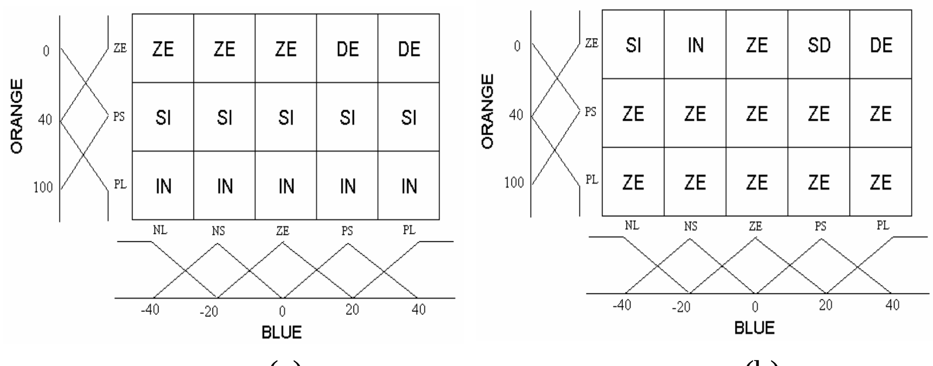


Figure 5 Control block diagram.

The membership functions of the fuzzy sets for the inputs are triangular functions with the finite supports as shown in Figure 6. Their linguistic variables are defined as NL (Negative Large), NS (Negative Small), ZE (Zero), PS (Positive Small), and PL (Positive Large). Here, for example, BLUE = NL means the size of the blue portion of the flame is very small compared to the desired size. The outputs are fuzzy singletons with the variables DE (Decrease), SD (Slightly Decrease), ZE (Zero), SI (Slightly Increase), and IN (Increase). For examples, AIR = SI means the controller should slightly increase the flow rate of the air. The supports of the fuzzy singleton for the air- and gas-valves, respectively, are {-100, -50, 0, 50, 100} and {-75, -40, 0, 40, 75}. The fuzzy rules are also given in Figure 6. The fuzzy control commands are determined through the minimum inference procedure. After that, the well-known center average defuzzyfication technique is used to calculate the non-fuzzy control commands.



(a) (b)

Figure 6 Fuzzy input functions and rules: (a) for the air-valve (b) for the gas-valve.

5. Results

Figures 7 and 8 show examples of the control results. In Figure 7 the flame initially started with very small size of both the blue and orange flames. The desired blue is set at the value of 25 (i.e., Blue* = 25). The results showed that the designed fuzzy logic controller is able to adjust the flow rates of the gas and the air to increase the size of the blue while maintaining the size of the orange to be minimum as desired. The time-history graph shows that the desired operating point can be automatically achieve within 13 seconds.

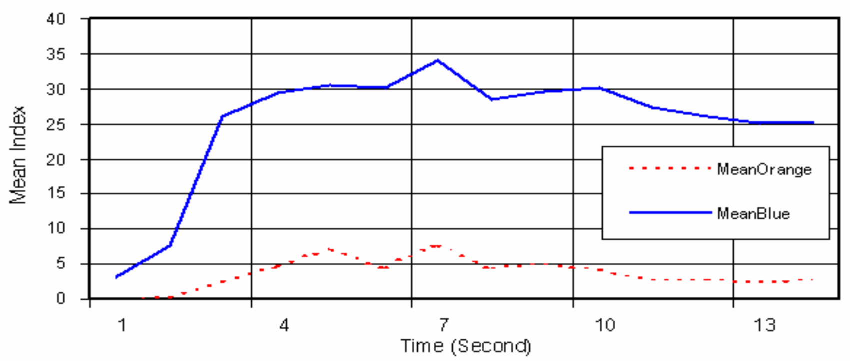


Figure 7 Control responses: Case1.

Figure 8 presents the control results of the second case when the initial size of the blue flame was larger than the desired size which is set to equal 10. Similar to the first case, the designed controller was able to adjust the flow rate of the gas and the air to decrease the size of the blue portion correctly and to reduce the orange to the minimum value in the same time.

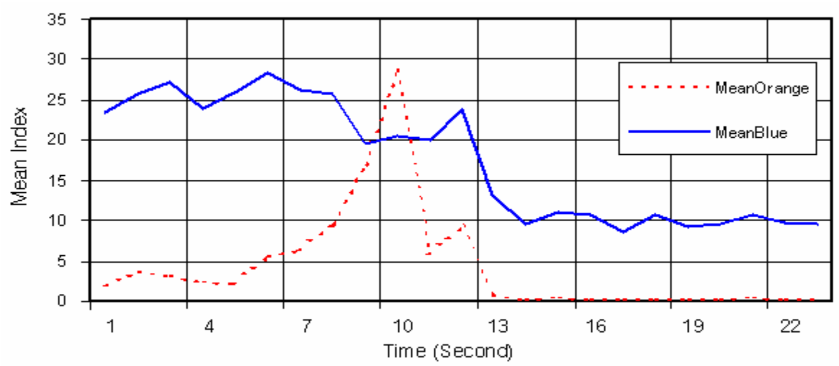


Figure 8 Control responses: Case2.

6. Conclusions

An experimental study of fuzzy logic control for a Meker burner has been presented in this paper. The control system consists of two fuzzy logics. The objective of the control is to achieve a good characteristic of combustion flame by visualizing the flame colors. The image of the flame captured by a CCD camera is processed in real time to extract the equivalent sizes of the blue and orange portions of the flame. These sizes are used to feedback to the designed fuzzy controller. The control results, in general, are satisfactory. The controller can regulate the flame to have the size of the blue portion of the flame as desired while minimizes the orange portion.

References

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