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Recognition of damaged letters based on mathematical fuzzy logic analysis

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ABSTRACT

This paper reports a real application whose task was to recognize characters printed on metal ingots. The problem is that surface of ingots is very uneven — ingots are hot or cold, cut by rough instrument, the printing machine can be worn down, etc. In this paper, we present two original recognition methods: the first one is based on application of mathematical fuzzy logic and the second one is based on representation of an image by a fuzzy-valued function. Results of these methods are compared with a simple neural network classifier and few other common methods.

1. Introduction

Character recognition is a unique ability of the human brain. For example, the authors in [12] say that "people and animals effortlessly identify objects even when the number of possibilities is vast, and we have no idea how this is done". However, though functioning of the human brain is not precisely known, it seems that a given pattern is associated with its meaning so that if an unknown character is figured out then one is able to guess its meaning and to find the most similar one. For example, even the very damaged letters depicted in Figs. 2, 6 and 5 below can be relatively easily be read by humans.

In this paper, we describe our solution of the character recognition problem for the case when characters are printed on a metal surface that is very uneven — ingots with the printed characters are hot or cold, cut by rough instrument, the printing machine can be worn down, etc. Consequently, the characters are usually very much distorted or damaged. The damage is additionally increased due to difficulties with distinguishing the characters from their background.

Note that our task challenges the principle of Turing test discussed in Pavlidis [11]: the letters on hot ingot are readable easily by humans but with great difficulties by computer. To cope with the level of possible damage, very robust methods are needed.

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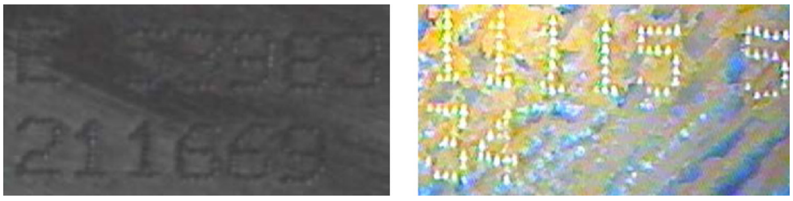

Fig. 1. Example of code printed on metal ingots. Left: hot ingot. Right: cold ingot.

We are aware that there are many methods in pattern recognition that could be used in our task. Because of the conditions of the industrial project, however, we were limited by time and none of the main available methods that we tried was satisfactory. Therefore, we decided to develop our own methods. Since they turned out to be very effective, we believe that they can be interesting to everybody who faces similar problems as we did.

The paper is organized as follows. After definition of the problem in Section 2, in Section 3, we describe a pattern recognition method based on an application of fuzzy logic with evaluated syntax. In Section 4, we describe another method whose main idea is to represent the image by a fuzzy-valued function. In Section 5, we briefly describe the results and problems of recognition using neural networks. Section 6 is devoted to comparison of the recognition results using both methods and also using neural network classifiers as well as few other common methods.

2. Description of the problem

The task contracted us by one Czech company was to recognize code printed both on hot as well as cold metal ingots. The code consists of characters from the standard alphanumeric alphabet and is printed in two lines consisting of up to eight characters [8]. The characters can be mutually shifted, distorted and damaged. Dimension (width and height) of each character is known with a certain tolerance. Image resolution is the same for one ingot type. Examples of both cases are in Fig. 1.

As outlined, the task can be split up into two subproblems: First, to separate the code from its background and second, to recognize the characters correctly despite their sometimes very severe distortion and damage. This paper focuses especially on the character recognition.

The pattern recognition methods can be divided into 11 groups (cf. [3]) such as data clustering, application of fuzzy sets, neural networks, structural or syntactic pattern recognition and others. We applied three methods for code recognition. The first one is based on the theory of mathematical fuzzy logic (more precisely, the fuzzy logic with evaluated syntax) and is very robust, so that even very distorted characters can be correctly recognized. The second one is a certain simplification of the first one and is based on representation of the image by a fuzzy-valued function. The third one is standard neural network based classifier. We discuss advantages of fuzzy logic approach in contrast with the traditional combination of neural network classifiers (the details can be found in [6]). In Section 6 we present results of our methods on a testing set. We included also some other methods such the license plate recognition based on syntactical analysis [7], CAPTCHA [2] and SSIM [13].

3. Recognition method based on mathematical fuzzy logic

The first method used for solution of the task described in the previous section is based on the theory of *mathematical fuzzy logic with evaluated syntax* $\mathrm{Ev}_{Ł}$ described in detail in [10]. The idea is to split the image into a grid of parts and to characterize each part both by its content as well as intensity. The content is characterized by a certain logical formula whose meaning can be, for example, that the given part is “a house, a pipe, a tree, a branch, a steep curve”, etc. or, of course, simply “a pixel”. This opens the possibility to