Automatic optical flank wear measurement of microdrills using level set for cutting plane segmentation

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1 Introduction

Automatic inspection of microdrill bits has become more and more important with the rapid growth of the printed circuit board (PCB) manufacturing industry, because of its strong impact on product quality. During inspection, drill wear measurement is one of the key tasks. Drill wear reflects the life cycle of a drill. A worn-out microdrill damages PCB surface finish and the dimensions of the drilled hole [1]. The tip structure of a microdrill bit is illustrated in Fig. 1. Drill inspection or wear measurement mainly focuses on the cutting plane which is also called the “first facet” or “lip relief plane”. The cutting lip and the chisel edge are the two important cutting edges among the four edges of a cutting plane. The cutting lips are the major cutting edges for material removal. Chisel edges located on the intersecting line of a cutting plane and a clearance, remove material by extrusion and cutting at a high negative rake angle [2].

Since the increasing circuit density brings about continuing microminiaturization of drill bits, the inspection has come to an enormous challenge. In the face of microdrill bits with a diameter of just one-tenth or even one-hundredth millimeter, it is obviously impossible to achieve the required inspection with the naked eye. The new dawn of this problem broke as automatic optical inspection (AOI) methods using computer vision technology were put forward. AOI relieves inspectors of the tedious job. Compared to manual inspection, it is time-saving, objective, and requires no contact [3,4].

AOI has been studied for more than two decades for microdrill bit inspection in PCB manufacturing. Some methods for defect inspection of microdrill bits were presented in [2,5,6]. These methods use edge detection or boundary extraction to segment a cutting plane from a microdrill bit image, and then corner detection and curve fitting are implemented to measure some features of a cutting plane. On the other hand, a scheme for flank wear measurement was reported in [1]. In this scheme, a two-dimensional edge detection technique is adopted for cutting plane segmentation; three features, flank wear area, average flank wear height, and maximum wear
height are employed to measure the flank wear. All the above-mentioned methods adopt simple edge detection or boundary extraction techniques, such as “Canny edge detector” and “SUSAN algorithm”, to segment the cutting plane. Cutting plane segmentation is a fundamental step in microdrill bits’ inspection. If cutting plane cannot be exactly segmented, it is impossible to obtain an accurate measurement result. However, these methods work well only in the case that the cutting plane is clear enough, as shown in Fig. 2a. In PCB manufacturing, the cutting plane of a microdrill bit can be stained by smearing. As shown in Fig. 2b, in the acquired microdrill bit image, the intensity level of the smeared part (inside the red rectangle) is similar to that of clearance, but much lower than that of other cutting plane parts. Furthermore, the boundary of the smeared part on cutting plane is also strong. So in these cases, it is difficult to distinguish between the smeared part of the cutting plane and clearance by conventional cutting plane segmentation methods. That is to say, it is still a challenge to exactly reserve the smeared part and completely block out the clearance in cutting plane segmentation. To solve this problem, we propose an approach using a level set for cutting plane segmentation. We also introduce a projection profile-based method for the feature measurement of flank wear and propose a new feature of flank wear, called “end wear length”, which experimentally has proved to be an effective index to evaluate drill life.

This paper is organized as follows. In Sect. 2, we give a brief description of a segmentation technique, called “level set”, used in this paper. Section 3 is dedicated to explaining the methodology used. Section 4 presents experimental results and discussion. Finally, some conclusions are drawn in Sect. 5.

2 Brief description of level set methods

Recently geometric active contour, or level set, has been a popular approach to address the problems of image segmentation in image processing and computer vision [7–11,19]. The level set method was originally proposed by Osher and Sethian [13] and has since been improved by many researchers [11,12,14,15]. The basic idea is to use the zero level set of an implicit function that is defined in a higher dimension as the representations of contours. This function is also referred as “level set function”, and can evolve according to a partial differential equation (PDE). There are many advantages of level sets for image segmentation [7]. Firstly, level sets can exactly represent regions and their boundaries on the pixel grid without the need of complex data structures, which considerably simplifies optimization by adopting variational methods and standard numerics. Secondly, parts of a region can split and merge in level set segmentation. Finally, a variational model is employed to describe the image segmentation problem, so the model will be more flexible, and additional features can be included to improve the segmentation. In this work, we employ a level set method for robust cutting plane segmentation. In the following, we will give a brief description of level set methods.

In level set formulation of active contours, consider a level set function \( \psi(x, y, t) \), as shown in Fig. 3a. The zero level of \( \psi \) is defined as the contour

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C = \{(x, y) | \psi(x, y, t) = 0 \} , \forall (x, y) \in \Omega ,
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