摘 要

在玻璃制造领域，由于机器、环境、生产工艺等原因，玻璃表面会出现结石、气泡、碎屑、划伤等不同类型的缺陷。这些缺陷的存在不仅会影响玻璃的美观性和质量，更存在诸多的安全隐患。对玻璃缺陷的准确检测和分类可以有助于及时发现产品质量问题以及造成缺陷的原因，从而以此为依据，改善制造条件，减少经济损失，防范安全隐患。

目前，基于计算机视觉的缺陷检测和分类方法是该领域的主流方法。视觉检测的结果相对于手工检测来讲更为客观，可有效的避免环境、人为等因素的影响，极大的解放劳动力；另外，视觉检测不需要昂贵的光学设备，只需要摄像机拍摄的产品图像作为输入，减少了设备开支；同时，视觉检测的结果更容易进行数据更新和结果保存，帮助工人及时发现生产设备可能存在的问题。

然而，基于计算机视觉的玻璃缺陷检测和分类技术面临诸多困难和挑战。对于检测来讲，光照条件的变化使得缺陷的成像差异较大，包括亮度、形态等均有所不同，而且图像上存在大量的噪声干扰，这对于缺陷定位的准确性和缺陷提取的完整性造成了很大的影响。对于分类而言，首先，缺陷的外观差异较大。不同类型的缺陷存在较大的外观差异，同类缺陷间的外观差异同样较大；其次，不同缺陷的成因不同，因而出现的频率也不同，特别是由于大量未定义缺陷的存在，造成了严重的样本不平衡问题。另外，划伤作为最常见的玻璃缺陷之一，综合其对比度、宽窄、形状、划伤相对位置等因素，其呈现的图像外观差异巨大，受噪声的影响也尤为显著。因此，划伤缺陷提取是缺陷检测中的一个极具挑战性的问题。针对这些问题，本文在研究通用的缺陷检测和分类算法的同时，同时对鲁棒的划伤缺陷检测和不平衡缺陷数据分类问题进行了探索。

论文的创新和主要贡献总结如下：

1) 针对划伤缺陷的特点，在“划伤缺陷在局部区域可近似为一条直线段”这一假设前提下，提出了一种从局部到全局的划伤缺陷检测策略，即首先在局部区域找到确定包含划伤缺陷的小窗口，进而对划伤窗口进行合并，最后通过对划伤区域的延展得到完整的划伤缺陷。该策略的优点在于只要划伤缺陷中的一个小的部分被找到，就可以通过延展等策略得到完整的划伤缺陷定位结果，并且，局部区域上的划伤窗口分析可有效避免噪声对划伤缺陷提取的影响；
2) 对于非划伤缺陷，提出了通用的缺陷检测和分类策略。在缺陷检测方面，通过逐行窗口扫描，对每个窗口进行灰度模式分析以得到疑似缺陷区域；进一步利用对比度增强实现准确的异常像素提取，获取准确的缺陷和未定义缺陷区域。在缺陷分类方面，以气泡、结石、碎屑缺陷的判别为例，结合三种缺陷以及大量未定义缺陷本质属性，设计了三级 SVM 分类器对其进行分类判别，其中，对于气泡、结石缺陷，提出分块 LBP 描述对结构性属性进行有效的刻画。最后，在基于学

习的分类方法后端，加入基于不同类别缺陷的形状及亮度规则限制，进一步提升了缺陷分类的性能。

3) 玻璃缺陷分类中未定义缺陷数量多、真实缺陷样本数量较少，导致训练样本严重不均衡。为在数据有限的情况下，提升分类性能，本文对不平衡数据分类问题进行了比较细致的调研，基于集成学习的思想提出了两种针对不平衡数据的分类策略：基于反例聚类的 SVM 集成分类策略和多特征集成的 SVM 分类策略，并通过实验验证了该策略的可行性和有效性。

关键词：玻璃缺陷；缺陷检测；缺陷分类；划伤缺陷；不平衡数据分类；支持向量机

Research on key technology in glass defect detection and classification based on computer vision

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In glass manufacturing, there are many kinds of defects on galss surface, such as bubbles, scratches, stones, chips and so on, becaues of the machine, environment, production process and other man-made causes. These defects not only influence the appperance and quality, but also bring many hidden trouble. The accurate detection and classification of glass defects can be conducive to discover the unqualified product and seek out the result of defects arising to reduce financial lose and precaution safety loophole.

At present, the mainstream methods for defect detection and classification are based on computer vision. The results got by computer vision inspection are more objective compared with manual inspection, and are more rubush to environmental variation. What's more, computer vision inspection dose not need expensive optical equipment. It just use glass image as input and can decrease the spending. At the same time, the result got by computer vision can be timely renewed and compared to quondam data to discover the potential problem.

But there are many difficulty and challenge to computer vision inspection. The change of lighting condition leads to considerable difference of defects, such as the luminance and shape. At the same time, there exsit many nosiy in the image, whict make it more difficult to localize the defects accurate and get the defects integrated. It is much hard to classify all different defects. Firstly, the difference of shape is large, even in the same class of defects. Secondly, the reasons of different defects are diverse, which lead to different emerging probability; meanwhile, there exist plenty of undefined defects, and as a result, the sample amount may be imbalance. Thirdly, as a common defect, scratch is totally different compaird with other defects, and is more sensitive to noisy. Hence the inspection to scratches is a challenge problem. According to these aporias, we research on a common method for defect detection and classification, while make an exploration on scratch inspection and defect classification on imbalance data set.

The innovations and contributions are as follows.

1) Specific to the character of scratch defect, we put forward a suppose that although the scratches may have various shapes, the small segments can be assumed to be a straight line in local. As a result, a local-to-global strategy is explored to realize the accurate detection of scratch. First is to determine the scratch segment on local windows through the hypothesis-test strategy. Then, the selected scratch windows are merged into several larger scratch regions according to the relative position relation. Finally, the extension stretching operation for each scratch region is performed to obtain much complete scratch defect. The biggest advantage of this solution is that so long as one segment of a scratch is found, the entire defect can be well extracted through the merging and

stretching operations.

2) We propose a common detection and classification method on non-scratch defects. When detecting on the glass image, by scaning each window, we analysis the gray pattern of the windows to get suspicious ones. Next, we extract the unnormal pixels by contrasten hancement and get exact true defects and undefined defects. When get the suspicious defects, we design a three-level SVM classifier to make classification to bubble, stone, chip and undefined defects. Partition LBP feature is designed to classify bubble, stone and undefined defects. After the classification based on learning, we add some rules on shape or luminance to promote the performance of classification.

3) In the tast of defect classification, there are much more undefined defects compared with real defects, which lead to the serious imbalance of sample amount. In order to promote classification performance using limited samples, we make a survey to classification problem on imbalance data set, and propose two methods using ensemble learning: SVM ensemble learning strategy based on negative clustering and multi-feature ensembling learning strategy.

Keywords: glass defect, defect detection, defect classification, scratch, imbalance data set, support vector machine