Constraint-Based Algorithm to Estimate the Line of a Milling Edge

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Abstract. Each practical task has its constraints. They limit the number of potential solutions. Incorporation of the constraints into the structure of an algorithm makes it possible to speed up computations by reducing the search space and excluding the wrong results. However, such an algorithm needs to be designed for one task only, has a limited usefulness to tasks which have the same set of constrains. Therefore, sometimes is limited to just a single application for which it has been designed, and is difficult to generalise. An algorithm to estimate the straight line representing a milling edge is presented. The algorithm was designed for the measurement purposes and meets the requirements related to precision.

Key words: constraint-based algorithm, line, milling, measurement.

1. Introduction

Image processing becomes increasingly popular in the area of quality inspection of furniture elements. It is applied in surface monitoring [4], wood defects detection [5] or tools monitoring [3, 6], among others.

One of intermediate wood products is a medium density fibreboard (MDF) which is a wood composite. The melamine-faced MDF is a single layer MDF covered with melamine. It is a commonly used material in furniture manufacturing [1].

Any imperfection in a surface, created by drilling or milling, reduces the value of a final product. One of the reasons of imperfections like delamination is the wear of tools used in machining the final product. To investigate the relation between the tool wear and the delamination, a delamination factor (explained for example in [7]) is usually analysed (see e.g. [6]).

A delamination factor can be calculated, for example, using the depth of chips or the area of chips as the measure of imperfection intensity. In massive analysed, the measurement of such coefficients without image processing would be labour-intensive, expensive, and subject to the risk of subjective judgement. To have repeatable and precise results, the task of measurement of the area and depth of chips should be performed with the use of an image analysis method.

The task of segmenting out the region which represents the chips on a milling edge is not an easy one. This region has, more or less, the same colour as the groove created by milling. It was observed that one of the ways to distinguish between these regions is the analysis of the spatial relationships. Pixels representing the chips are between the milling edge and the untouched melamine. It should be taken into account that on the samples produced with new mills there can be no chips at all.

An algorithmic approach suggests to find what is invariant. In the analysed case, in all samples, the groove and the melamine is always visible. This makes it possible to reduce the problem of indicating the pixels which represent the chips to finding the pixels between the line representing the edge of the milling and the melamine. If there is no delamination, there is nothing between these objects and the delamination factor is equal to zero. When the delamination appears, the border line of the untouched melamine is no longer straight and it cannot be treated as the milling edge.

The object to be estimated is the line representing the milling edge. A common approach to estimating a straight line in a picture is the Hough transform [2]. It is a robust method based on voting of pixels potentially belonging to the line to be detected. In the case of our interest it is not easy to apply that method. Typically the edge detection filter is applied and then pixels having a value above a chosen threshold are used to vote. However, because the difference in brightness between melamine and the remaining part of the image is quite significant, this would generate the set of voting pixels from those on the border of melamine. In consequence, the estimated line would be shifted. Although there is a shadow related to the depth of the groove, it is subtle and not regular enough to be treated as invariant.

To handle the problems mentioned above, in Section 2 the input data and the examples of important aspects related to the difficulties in the described problem will be analysed. In Section 3 a simple and fast algorithm which handles all of the mentioned problems will be presented. At the end, some of the results of application of the algorithm to the data will be shown.

2. Material

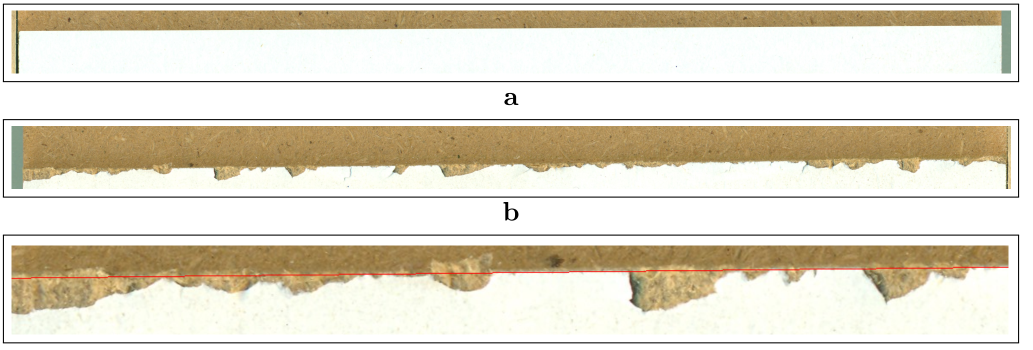
In the analysis, the pictures of melamine-faced MDF were used. It is important that we have considered the delamination of various intensities, including the large intensities never occurring in the industrial practice. This was done in order to test the proposed delamination factor measurement method in typical as well as in extreme working conditions.

There were 450 samples of MDF pieces 10×16 cm. On each sample there were three milled edges (one groove with two edges and one single-sided groove, both 5 mm deep). The details interesting from the wood processing point of view have been described in [6]. The samples were scanned with 600 dpi. Examples of scanned samples are presented in Fig. 1. From each scan, three pictures were taken and rotated if necessary. In this way,

Fig. 1. Examples of scanned samples: (**a**) milled with a new tool; (**b**) milled with a very used-up tool.

1350 images 3840×240 pixels were produced for analysis. Each image was rotated in such a way that the melamine was at the same side (in the visualisation in Fig. 1 it is at the right-hand side). The coordinate y increased from the side of the groove towards the melamine side (to the right in Fig. 1). The general layout of the cutting edges was the same in each image; hence, instead of performing three times the detection of edges at the sides of a groove, it was necessary to perform three times the task of detecting a well-defined edge.

In Fig. 2 the examples of difficulties encountered in the measurements are shown in magnified images. The first problem is that the milling line is not horizontal so its position changes in the y direction (Fig. 2a, b), so the line itself should be detected. The second problem is that if delamination appears, the edge between melamine and darker regions is not straight, although the milling line was so. This is the reason why the edge cannot be analysed locally.



a

b

c

Fig. 2. Examples of difficulties to solve: (**a**, **b**) the milling line is not horizontal; (**c**) the delamination makes the edge heavily depart from being straight.

3. Algorithm

Constrains generally have two aspects. The first aspect is that constrains limit the freedom, the set of possibilities. The second aspect is that they allow to reject wrong hypotheses. By using the constraints it is possible to design effective algorithms. The computations can be speeded up and better results can be obtained. An example of an algorithm to detect trees in LIDAR data in which constraints were taken into account can be found in [8].

In the case of our interest an algorithm to estimate the straight line which represents the milling edge was needed. The result of the algorithm had to be precise enough to be used for the measurement purpose. As long as milling removes some of the melamine, the constraint was defined such that pixels representing melamine cannot occur inside the area of a groove. At the same time, the pixels representing melamine should belong to the edge except the cases where delamination occurred. An assumption was made that at least two pixels representing melamine were preserved at the edge. Even in the worst cases of delamination, the number of such pixels is much larger.

In other words, the algorithm had to find a straight line that *touches* as many of the pixels representing melamine as possible, but containing no pixels from the other side of the line, where the darker material of the inside part of the specimen is visible.

3.1. Preprocessing

Under the assumptions given above, it was enough to take for the further analysis only the pixels representing the boundary of the melamine area. It is assumed that the boundary extends over the major part of the image (at least there are pixels of the cutting line in both halves of the image). It is assumed that the cutting line is close to horizontal (very roughly) so it can be parameterized with the variable x, with the axis Ox pointing to the right, and the axis Oy points down (melamine is in the lower part of the image, like in Fig. 2). To prepare the required information, the preprocessing steps described below were executed.

1. Recognize the pixels representing melamine by selecting pixels brighter than a chosen threshold (200 in all RGB channels) and create a binary image.
2. For each x, take the minimum value of y representing melamine.
3. If the value of y is 0 then this is the margin (the region of interest including the edge was taken with a margin to compensate for an imprecise placement of the sample on the scanner); such points will be further excluded from the analysis.

In this way, an array Y_x of numbers was formed in which indexes represent subsequent values of x (in pixels) and values represent the minimum value of y coordinate of melamine pixels for current x.

3.2. Edge detection

The algorithm is described below.

1. Find x_0 that has the minimum value of y.
2. Check whether x_0 is in the left or in the right half of the image. The steps below describe the case when this pixel is on the right (if it is on the left then the algorithm below goes in the opposite direction, that is, from larger to smaller values of x).
3. Set x_1 as the first pixel on the left in the axis Ox (the smallest x possible).
4. Move x_1 to the right until the first local minimum of Y_x is found.
5. Use the equation of the line passing through two points $(x_0, Y_{x_0}), (x_1, Y_{x_1})$ to calculate its coefficients. This line represents the current position of the cutting line.
6. Verify if any point in Y_x violates the constrains (if for any x_i it is $Y_{x_i} < y$, where $y = a(x_i) + b$, and a and b are the coefficients calculated in step 5). Check this condition going in the same direction as previously (here, to the right). If a violation occurs, repeat from step 4. Otherwise, proceed.
7. Return the coefficients.

In the verification in step 6 it is taken into account that pixels have integer coordinates and the line equation gives real values.

The iterations of the algorithm are illustrated in Fig. 3 (to make it possible to enlarge the images to the maximum extent they have been turned left by a quarter of a revolution, so now Ox points up and Oy points to the right). The current position of the line is marked in red. The two points are marked with black arrows, with x_0 in a constant position and x_1 moving towards larger values of x from one iteration to another. The point in which the assumptions are violated is marked with a blue arrow. The line is not widened for the illustration due to that this would obscure the view of single pixels, which are very important in this algorithm.

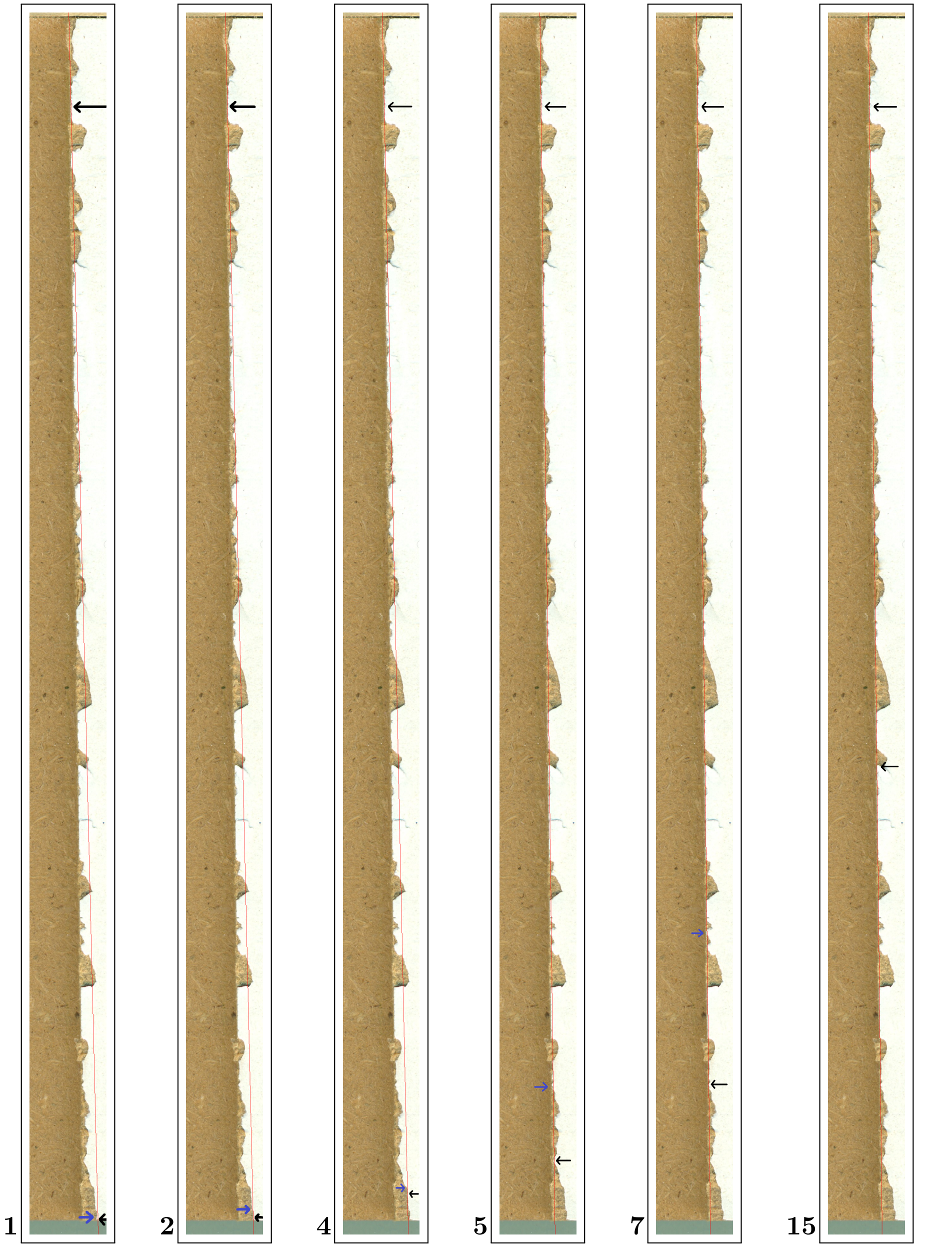


Fig. 3. Selected iterations of the algorithm: 1, 2, 4, 7, 15 (the last one). See also text.

4. Results

The algorithm was tested on a set of 450 samples, three images for each, making 1350 images (these images were used in the analysis of the delamination factor described in [6]). The correctness of the results was verified by inspection of the images with marked pixels representing the boundary of the melamine region and the line representing the milling edge. The results in all 1350 images were assessed as well marked. Some of the assessed results can be seen in Fig. 4.

5. Conclusion

Constraint-based algorithms usually have the advantages of accuracy and speed. The algorithm proposed in this paper fits this scheme. It is fast, has a simple structure, and returns correct results. All of those objectives were obtained as a consequence of the proper analysis of the problem and appropriate definition of constrains. At the same time, a constraint-based algorithm usually has a limited area of applicability and it is difficult to be generalized. The algorithm proposed was designed to solve the well-defined task on a large set of similarly structured, but varied images. It gave proper results for all the images in that set, which made it possible to effectively solve the technical problem posed by a practical application.

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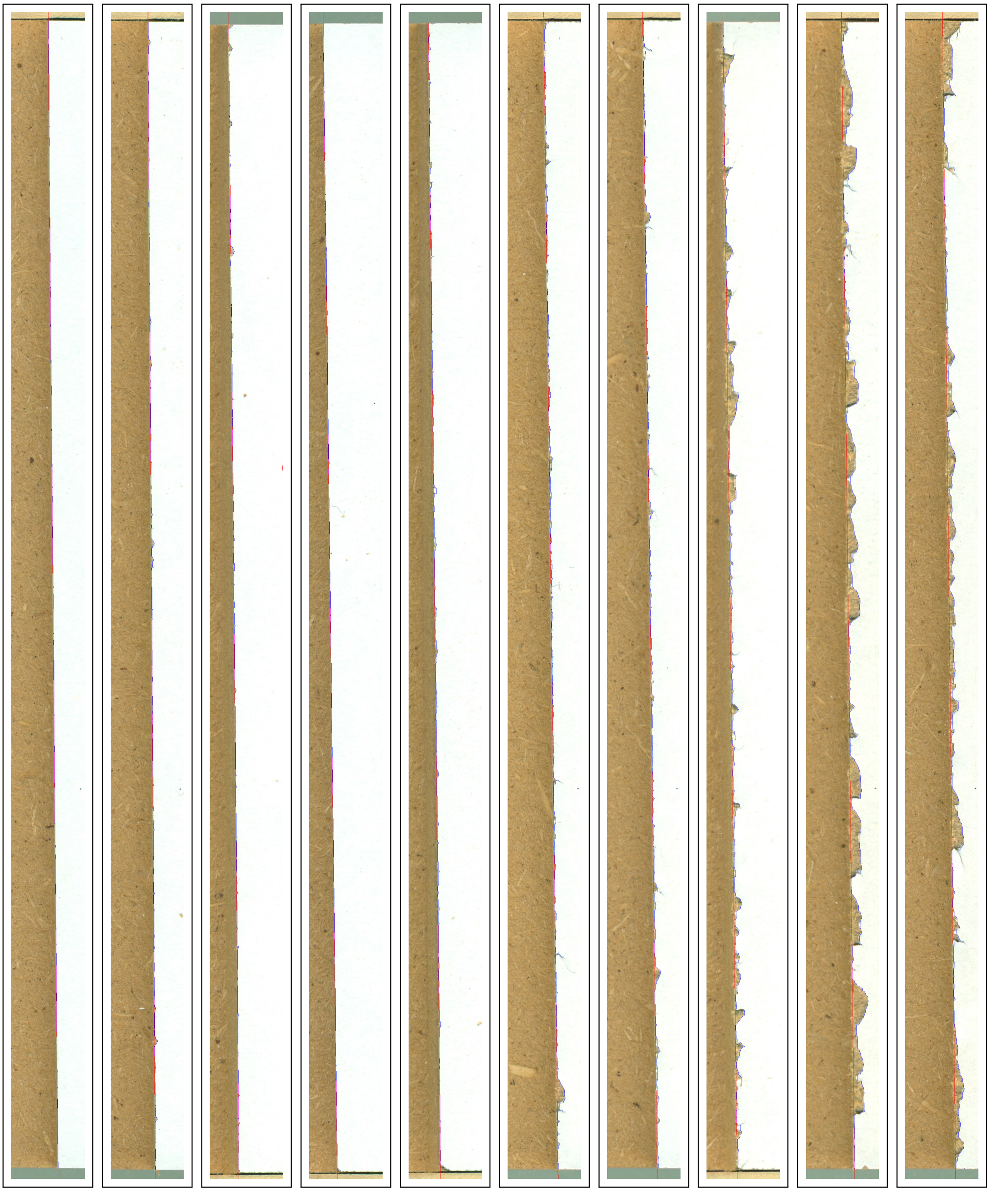

Fig. 4. Examples of images used to evaluate the correctness. Colours of pixels: blue – pixel on the border of melamine, red – estimated line, purple – overlap.

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