EXTRACTION OF GEOMETRICAL PRIMITIVES FROM A SET OF CONTOUR POINTS

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Abstract:

This paper proposes a method of evaluation for contour points. Based on the coordinates of the points a classification of each point is performed which results in groups of points that supposedly make up a primitive geometry (e.g. a circle or a line segment). When combined with adequate fitting techniques as post-processing this directly yields primitive geometrical features of the object, like center and radius of a circular (sub-)structure, without manual specification of an area of interest.

Keywords: Intelligent measurement, Geometrical primitives, Feature recognition, Feature extraction

1. INTRODUTION

One of the most common tasks in digital image processing is the measurement of geometrical features in an image. Most approaches to achieving this goal rely on the specification of an area of interest that contains the feature. The definition of this area has great influence on the result of the calculation. A larger area can reduce the margin of statistical error whereas an area of interest that covers other structures as well can introduce systematic errors. Additionally the relative position and rotation of the pixel raster (image sensor), the feature itself and the area of interest can influence the results of the edge detection algorithm that the feature measurement is based on.

2. STATE OF THE ART

Especially searchline based detection methods rely heavily on an area of interest since the calculation of the one dimensional grayscale signal depends on the start and end of each searchline [1]. For measurement of geometrical features the individual searchlines are positioned by transforming a standardized pattern onto the area of interest [2].

The standard approach for the definition of such an area of interest as an essential parameter for the measurement either is based on an interaction with the user or the area of interest is calculated from previous measurements and a priori knowledge about the object [3]. The steps a user has to perform to define it vary depending on the design paradigms the software was developed by concerning its handling. Nevertheless the process is time consuming and requires substantial knowledge about optical measurement basics and about the mode of operation of the software that is used. Thereby it allows for considerable user influence on the measurement result.

3. OBJECTIVE METHOD OF MEASUREMENT

3.1 General approach

In order to remove the influence of the area of interest from the measurement, there are two possible solutions. Either the area is to be generated automatically or the measurement must be performed utilizing a method that does not rely on this user input altogether. The method this paper proposes does not take an image as its input, instead it uses a set of contour points and tries to classify the points effectively extracting subsets of points that make up local geometrical features. Since the number of excess points is not a problem, the whole contour of an object can be detected using standard means of tracing. Afterwards the proposed algorithm can be used to identify relevant areas.

In general the procedure consists of a series of steps that take the set of contour points as their public input. Therefore there are two modes of operation that can be implemented. For one it is possible to use a minimized user interaction which only consists of the selection of a contour for example by a single click. Afterwards the contour can be traced to produce a suitable set of points. The alternative is the automated detection of a suitably dense cloud of contour points for example by a grid of searchlines. These points can be separated into groups each corresponding to a single contour using a spatial segmentation algorithm. After that each set of points can be sorted to restore their order and the proposed extraction method can be applied.

The classification itself is performed by following a sequence of processing steps as shown in Fig. 1. More detailed explanations to the individual processing stages can be found in the following sections.

3.2 Pre-processing

The algorithm this paper proposes is based on signal processing of discrete signals that represent the contour. Therefore the original input data is an ordered sequence of points. Each of these points presents a set of coordinates that are used to create discrete signals representing the course of the individual coordinates along the contour.

Since each single point is subject to random error the signal usually contains an amount of noise which has considerable impact on the subsequent calculations. Therefore low-pass filters are applied to smoothen the signal.

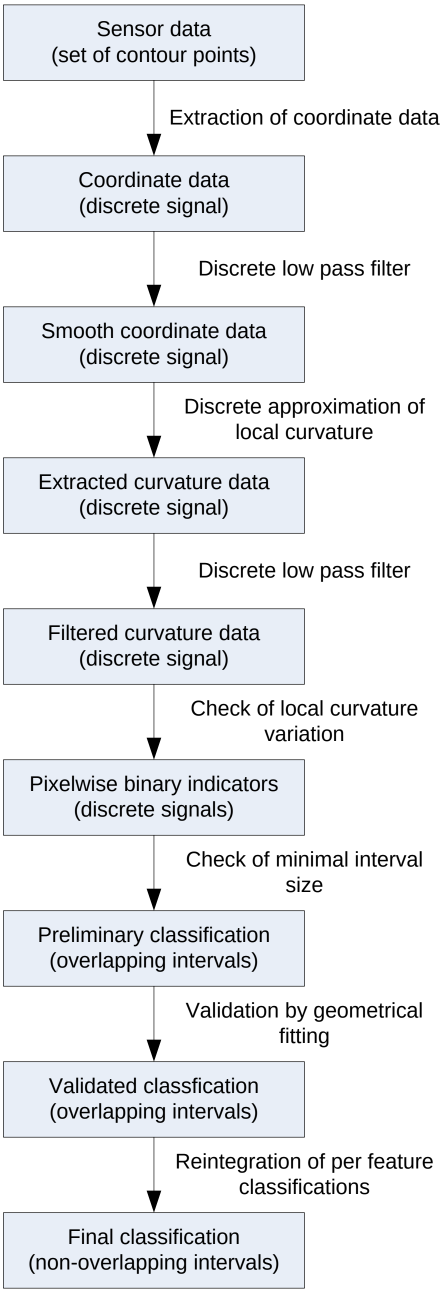
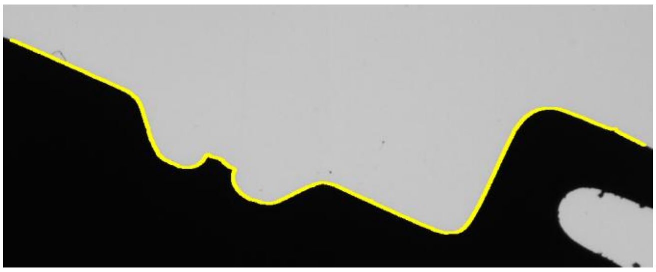


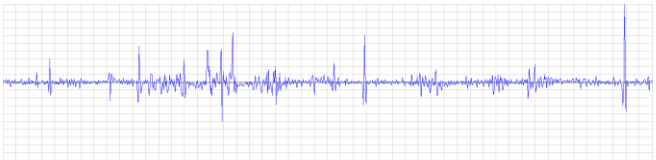
Fig. 1: Flowchart of the individual processing stages of the proposed method showing calculations involved as well as their results

The next step is the calculation of the signal which actually will be used for classification – the curvature of the contour. For each point the direction of the local tangent in the smoothened contour is calculated. The difference in their angle of rotation is then taken as the local curvature information. This introduces a large amount of noise into the curvature signal (see Fig. 2(b)). Therefore an additional step of low-pass filtering is applied at this stage generating a relatively smooth discrete signal which can be used for the classification process (Fig. 2(c)).

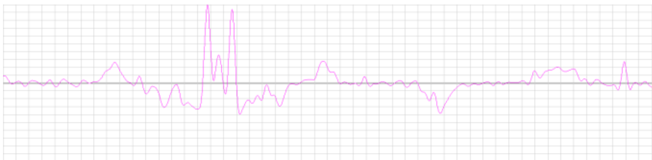
Comparative experiments indicate that triangle filters are the most appropriate for both filtering steps. A box filter does not remove the highest frequencies in a sufficient manner whereas a Gaussian filter needs to use a very wide filter core to create a suitable signal. Hence it takes a lot of computation time without considerable beneficial effects in the resulting curvature signal. The application of nonlinear filters like a median is not advisable. The assumption that the total curvature of the whole contour is fixed despite the filtering would be compromised.



(a) Original set of contour points (yellow)



(b) Calculated curvature signal (function of contour point index [orientation in contour: left to right], blue, scaled to 1.0)



(c) Filtered curvature signal (function of the contour point index [orientation in contour: left to right], violet, scaled to 1.0)

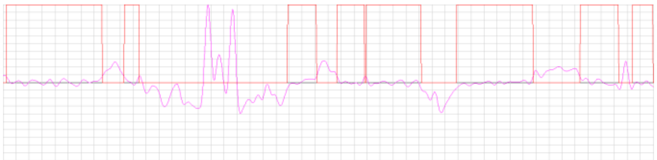
Fig. 2: Calculation process of discreet signals

3.3 Local indicators for geometrical features

The most basic tasks besides detecting a single point are the measurement of a line segment or an arc. These two local geometrical features share a common characteristic that can be exploited to detect them: a constant curvature. An ideal line segment has a curvature that equals 0 whereas for a circular region the value is non zero yet constant.

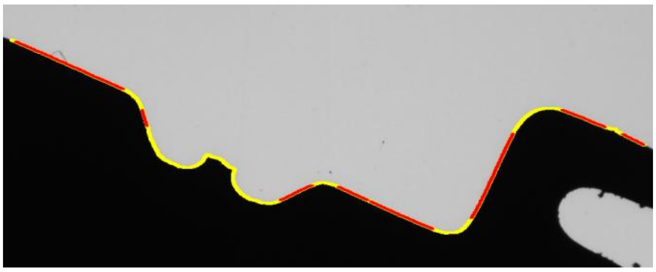
Since the original curvature signal contains noise, an image of a real object does not result in a locally constant curvature value. Therefore the criterion for local constancy is based on a threshold of difference resulting in a local range of acceptable curvature values. This approach tolerates low level deviation from the ideal geometrical form.

A geometrical primitive cannot consist of a single point only. Hence the additional requirement for classification of a region as a certain primitive is a minimum number of points involved where the lowest accepted number depends on the kind of geometry. The necessity for this does not arise from the fitting calculation but from the assumption of continuance of local form. If the object contains very small features the contour points might need to be sampled more densely to compensate.

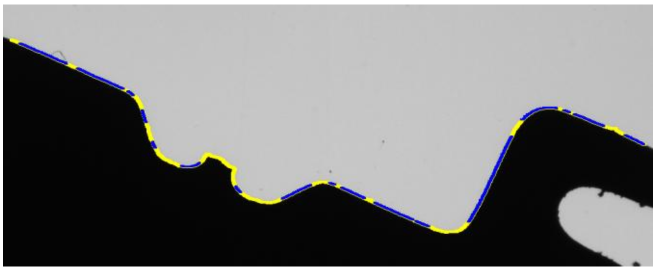


(a) Filtered curvature signal (function of contour point index [orientation in contour: left to right],violet, scaled to 1.0) and binary indicator signal for line segments (function of contour point index [orientation in contour: left to right], red)

(b) Filtered curvature signal (function of contour point index [orientation in contour: left to right],violet, scaled to 1.0) and binary indicator signal for circular segments (function of contour point index [orientation in contour: left to right], blue)



(c) Regions preliminarily classified as a line segment (red) and the remaining contour points (yellow)



(d) Regions preliminarily classified as an arc (blue) and the remaining contour points (yellow)

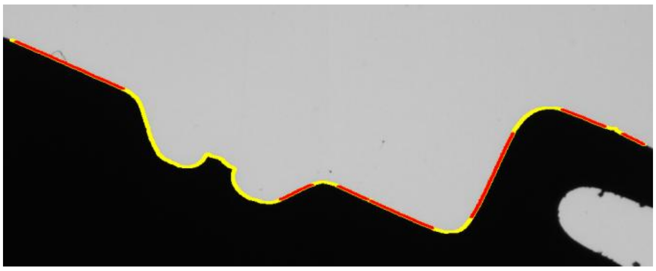
Fig. 3: Feature indicators and classified regions

3.4 Validation

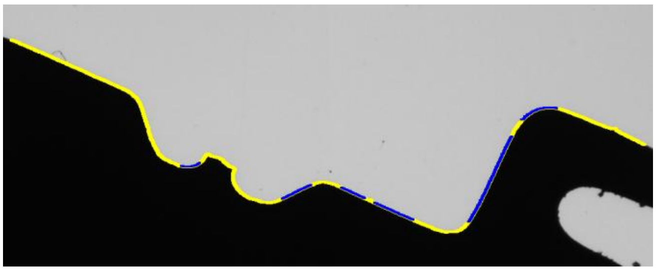
The indicator based procedure classifies each point as part of a line, part of a circle, part of a line and a circle or as an undefined region. Due to the required minimum number of points for local classification there are no isolated points classified as a geometrical feature. Instead the classification divides the contour points into subsets that supposedly represent geometrical primitives. Two adjacent regions that were classified as the same type of geometry but not the same feature would cause problems. Nevertheless this scenario does not pose a problem since it cannot occur due to the low-pass filtering. Adjoining line segments as well as neighboring arcs create an area of non constant and nonzero curvature between them. This results in a few points between the features that are classified as an undefined region.

The method often leads to false-positive classification results as shown in Fig. 3. Thus a validation step that removes these is mandatory. The result of this elimination process is presented in Fig. 4.

The decision whether to keep the classification of a set of points or to discard it is made based on the results of geometrical fitting. Besides standard deviation and form error there are also relevant parameters in the resulting geometry. An arc that only covers a small angle for example is very likely to actually be part of a line. This kind of error is caused by the acceptance tolerance for local constancy of curvature and can be corrected during validation and the following step of reintegration.



(a) Validated regions classified as line segments (red) and the remaining contour points (yellow)



(b) Validated regions classified as circular regions (blue) and the remaining contour points (yellow)

Fig. 4: Remaining classified intervals after validation

3.5 Reintegration

The initial classification and the validation steps are performed individually for the different kinds of geometrical primitives in question (line segment and arc/circle). The last step of the extraction procedure is to combine the results of these parallel calculations. Overlapping between contour point intervals that are classified as lines and arcs is an error in calculation therefore the individual results need to be corrected to compensate this. A suitable criterion for the final classification of points with ambiguous affiliation is the size of the primitives. The validation process is more reliable for larger structures hence including the uncertain points there is more likely to be correct. Determination of point set affiliation can also be done using fitting parameters as the deciding criterion. Higher standard deviation and form error or small angles in arcs can indicate false-positive class membership. Alternatively the ambiguous points can also be set to undefined.

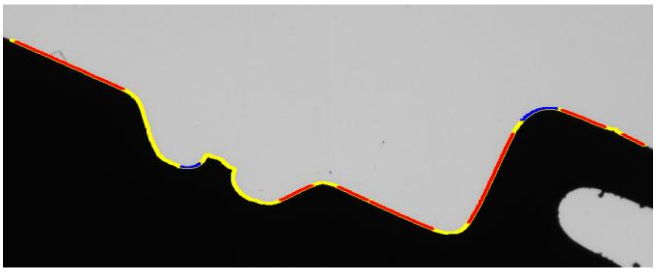


Fig: 5: Classification result after reintegration (red – line segment, blue – circular region, yellow – unclassified)

4. DISCUSSION OF PERFORMANCE

The method presented above has a great number of internal parameters that can be used to tweak its performance. If their values are not adapted to the objects the method is applied to, poor results are to be expected.

For testing purposes a set of cutting edges has been used as samples. Measurement of the contour points was performed using a camera system for metrology and digital image processing software that can locate edges at subpixel precision.

In order to adapt the algorithmic parameters it is necessary to specify an objective function for optimization. For preliminary testing an unweighted pointwise comparison of the results the system produces using a certain set of parameters and a manual classification of the contour is used. The parameter values have been adapted manually which means that there might be potential for further improvement.

The results of the test indicate that the overall classification result is good but not yet good enough for real world applications (especially for automation) where the objects in question show greater variance and potentially suffer from perturbation. The overall classification rate for the sample set of object was at 80-90%.

Although the pointwise classification rate is somewhat unsatisfying, most features could be detected. Therefore the test results so far indicate that it is possible to remove the user interaction of defining an area of interest from the measurement at least for a significant portion of the available features. It is to be determined whether the algorithm can be enhanced to enable an overall automatic feature recognition and measurement. Nevertheless it can be used to speed up manual measurement by providing a set of automatically detected features that do not need any time consuming and potentially error prone user interaction for measurement.

5. PROSPECTS FOR ENHANCEMENTS

Since the results of the new approach are not yet satisfying the method will be modified during ongoing research. A starting-point is a more objective way of parameter optimization. General techniques for optimization of nonlinear functions will be tested. If such an algorithm was applicable to the problem an adaption of the classification system to a totally new set of samples would only consist of a few relatively simple steps as commonly seen in training procedures for established vector classification systems.

Furthermore different optimization targets will be tested. Introducing weights into the comparison based on the size of the intervals might make for a better detection rate of features. Small features consist of few points so the penalty for not finding these is relatively small as well. Depending on the application it might be more desirable to lose a few points of some larger features but miss less of the smaller ones. A distinction between false-positive and false-negative penalties could also be considered.

Besides a new adaption process of the existing parameters the method itself will also be modified. Additional steps of post-processing are conceivable. Occasionally a feature is classified as more than one interval as seen in Fig. 5 where the two line segments on the right should be connected. It might for example proof helpful to try reconstructing such split features. Another point would be to test the intervals for expandability. This would reduce false-negative classification at feature limits.

REFERENCES

[1] O. Kühn, “Contribution to high resolution two dimensional measurement of geometry with CCD line scan sensors”, Dissertation, Ilmenau University of Technology, pp. 13-22, 1997

[2] Mahr OKM GmbH, Manual of metrology software Osprey

[3] J. Bergmann, “Edge detection in image processing measurement”, Quality Engineering, vol. 05/2005