User's Manual

ActivFeatureCalc

The Blob Analyzer

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More information about ActivVisionTools can be found at:

`http://www.activ-vision-tools.com`

How to Read This Manual

This manual explains how to use ActivFeatureCalc to analyze the objects extracted by ActivBlobFinder. It describes the functionality of ActivFeatureCalc and its cooperation with other ActivVisionTools with Visual Basic examples. Before reading this manual, we recommend to read the manual Getting Started with ActivVisionTools, which introduces the basic concepts of ActivVisionTools, the User's Manual for ActivView to learn how to load and display images, and the User's Manual for ActivBlobFinder, which explains how to extract the objects you want to analyze.

To follow the examples actively, first install and configure ActivVisionTools as described in the manual Getting Started with ActivVisionTools. For each example in this manual, there is a corresponding Visual Basic project; these projects can be found in the subdirectory `examples\manuals\activfeaturecalc` of the ActivVisionTools base directory you specified during installation (default: `C:\Program Files\MVTec\ActivVisionTools`). Of course, you can also create your own Visual Basic projects from scratch.

We recommend to **create a private copy of the example projects** because by experimenting with the projects, you also change their *state*, which is then automatically stored in the so-called description files (extension `.dsc`) by ActivVisionTools. Of course, you can restore the state of a project by retrieving the corresponding description file from the CD. !

Contents

Chapter 1

About ActivFeatureCalc

This chapter will introduce you to the features and the basic concepts of ActivFeatureCalc. It gives an overview about ActivFeatureCalc's *master tool* and its *support tools*, which are described in more detail in chapter 2 on page 17.

1.1 Introducing ActivFeatureCalc

With the help of ActivFeatureCalc you can inspect the blobs extracted by ActivBlobFinder by analyzing various *shape and gray value features* of the blobs. These features describe the appearance of a blob, and thereby the corresponding object, from various "point of views": For example, features like `Mean` or `Contrast` describe the texture of an object, while features like `Center Row` and `Center Column` describe its position.

The currently available features are described in section 1.1.1; section 1.1.2 on page 13 shows which features can be converted to other units besides pixels, while section 1.1.3 on page 13 takes a closer look at what happens if you use ActivFeatureCalc together with ActivAlignment.

The results of ActivFeatureCalc, i.e., the values of the calculated features for each blob can be displayed using ActivDataView or ActivFeatureHistogram and then further evaluated using ActivDecision, before you output them via ActivFile, ActivSerial, or ActivDigitalIO; furthermore, you can access results via the programming interface (see section 4.2 on page 34).

1.1.1 The World of Features

Position

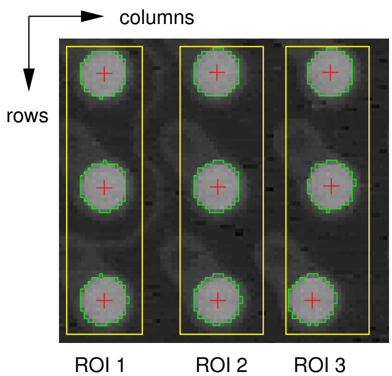
In ActivFeatureCalc, the position of a blob can be calculated by determining the *center of gravity* of the corresponding area in the image, i.e., the features `Center Column` and `Center Row`. In figure 1.1 the position of nine elements of a ball grid array (*BGA*) is calculated; the wrong position of the ball in the lower right corner clearly shows up in the column coordinate. Please note that the accuracy of the calculated center of gravity depends on the number of pixels of the blob; see below for similar features which can be used for small objects.

Size and Extent

The size or `Area` of a blob is typically calculated by determining the number of pixels within the blob region; if the blob has holes, the corresponding pixels do not contribute to the overall area. For the feature `Area Convex` the area of its *convex hull* around the blob is determined, including all holes. See figure 1.2 for an example.

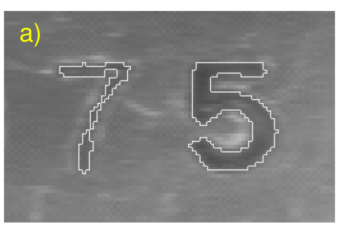
ActivFeatureCalc allows to measure the extent of a blob in different ways: The features `Height` and `Width` correspond to the extent along the image axes (see figure 1.3a on page 4). These features are easy to calculate, but are affected by the orientation of the blob. In other words, if the inspected object rotates slightly, `Height` and `Width` may change significantly.

Alternatively, ActivFeatureCalc calculates the features `Major Extent` and `Minor Extent`, which correspond to the extent of the smallest rectangle surrounding the blob (see figure 1.3b



Roi Id	Object Id	Center Row	Center Column
Rectangle1_1	0	42.516	164.603
Rectangle1_1	1	72.600	164.723
Rectangle1_1	2	102.672	164.724
Rectangle1_2	0	42.202	194.519
Rectangle1_2	1	72.548	194.644
Rectangle1_2	2	102.485	194.776
Rectangle1_3	0	42.234	224.625
Rectangle1_3	1	72.267	224.809
Rectangle1_3	2	102.474	219.830

Figure 1.1: The center of gravity.



Object Id	Area	Area Convex
0	115.000	328.000
1	371.000	607.000

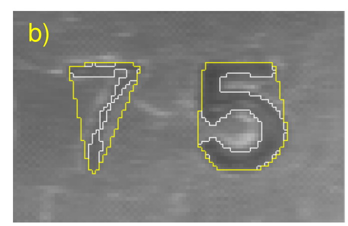


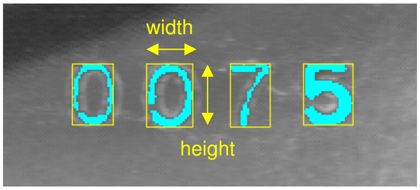
Figure 1.2: The (a) area and (b) convex area of a blob.

on page 4). These features are more robust against changes of blob orientation. However, small changes in the distribution of pixels (like small "hairs") may "tilt" the rectangle; for example, the rectangles surrounding the two zeroes in figure 1.3b on page 4 have a different orientation though the zeros look similar to the human eye.

A third method to calculate the extent first determines the *equivalent ellipse* and returns its radii in the features `Major Radius` and `Minor Radius`. The equivalent ellipse has the same *moments of inertia* as the blob, i.e., offers the same resistance to being rotated around the two principal axes; its center is the center of mass (see appendix A on page 47 for the mathematical background). These features are robust against changes of the blob orientation and of the distribution of pixels (compare the zeroes in figure 1.3b and figure 1.3c). Please note that the accuracy of the ellipse parameters depends on the number of pixels of the blob; see below for similar features which can be used for small objects.

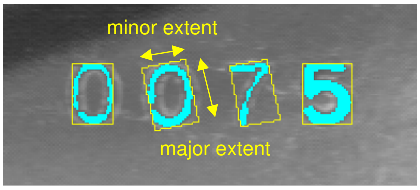
Finally, ActivFeatureCalc offers to calculate the radius of the smallest surrounding circle (`Radius Outer Circle`) and of the largest circle fitting inside the blob

a)



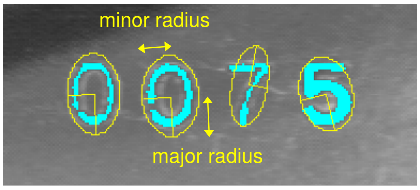
Object Id	Width	Height
0	19.000	28.000
1	21.000	29.000
2	18.000	29.000
3	23.000	28.000

b)



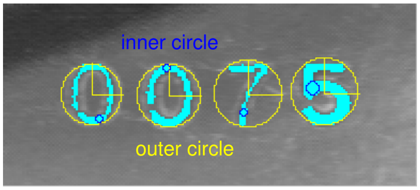
Object Id	Major Extent	Minor Extent
0	28.000	19.000
1	29.221	20.592
2	28.629	17.865
3	28.000	23.000

c)



Object Id	Major Radius	Minor Radius
0	19.143	12.257
1	18.651	12.934
2	19.421	8.089
3	17.719	12.445

d)



Object Id	Radius Inner Circle	Radius Outer Circle
0	2.375	15.000
1	2.250	15.000
2	2.469	16.000
3	3.766	16.000

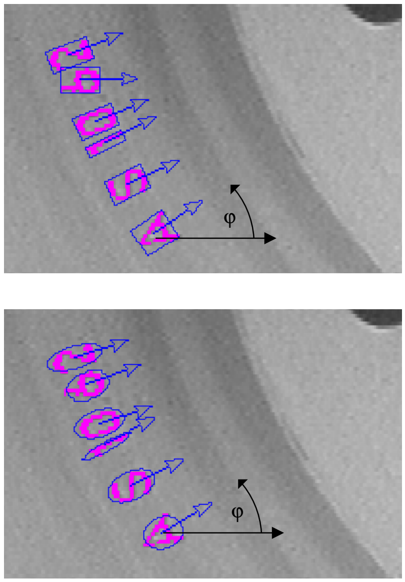
Figure 1.3: The extent of a blob: (a) along the image axes; (b) the extent of its smallest surrounding rectangle; (c) the radii of its equivalent ellipse; (d) its inner and outer circle.

(`Radius Inner Circle`), as depicted in figure 1.3d.

Orientation

In fact, a blob by itself has no orientation; however, ActivFeatureCalc lets you determine the orientation with the help of two intermediate constructs: the *smallest surrounding rectangle* and the *equivalent ellipse*. In figure 1.4, these two methods are used to determine the orientation (`Orientation Ellipse` and `Orientation Rectangle`, respectively) of characters on the circular rim of a part. In both methods, the orientation is `0` if the major axis of the rectangle or

a)



Object Id	Orientation Rectangle
0	21.801
1	0.000
2	21.801
3	26.565
4	23.962
5	33.690

b)

Object Id	Orientation Ellipse
0	17.956
1	19.391
2	17.996
3	29.204
4	26.750
5	30.999

Figure 1.4: The orientation of (a) the smallest surrounding rectangle and of (b) the equivalent ellipse.

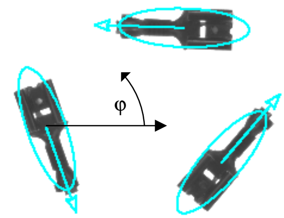
ellipse is parallel to the horizontal axis.

The example in figure 1.4 was chosen on purpose to show that neither method is "perfect" in the sense that it yields the desired results in all cases. Thus, `Orientation Rectangle` "fails" for the digit 6, `Orientation Ellipse` for the digit 1. The reason for this behavior is (obviously) not that the methods are poorly implemented, but more fundamental: The digits in question are not described well by the smallest surrounding rectangle or equivalent ellipse, respectively.

Because of their symmetry, both the smallest surrounding rectangle and the equivalent ellipse only calculate angles in the range `+/-90`°. In contrast, the feature `Orientation` allows to calculate angles in the range `+/-180`°. For this, the underlying algorithm computes the equivalent ellipse; furthermore, it determines the point on the contour with the biggest distance to the center of gravity and uses it as a sort of reference point. Note that this method only works well for objects which are roughly symmetrical to their major axis but not symmetrical to their minor axis, like the plugs examined in figure 1.5.

Contour

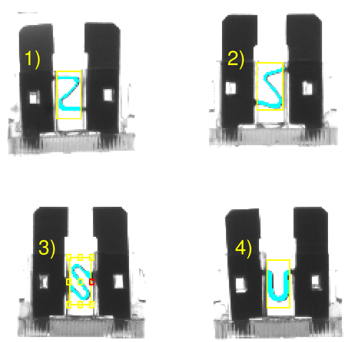
To describe the contour of a blob, i.e., its boundary, ActivFeatureCalc calculates the `Con-`



Object Id	Orientation
0	178.197
1	-70.488
2	49.354

Figure 1.5: Calculating the orientation in the range `+/-180`° .

`tour Length`. The distance between two neighboring contour points parallel to the coordinate axes is rated as `1`, the distance along the diagonal as $\sqrt{2}$. Note that only the “outer” boundary is analyzed; holes within the blob are disregarded.In figure 1.6, the feature `Contour Length` is used to analyze fuse wires in different types of car fuses.

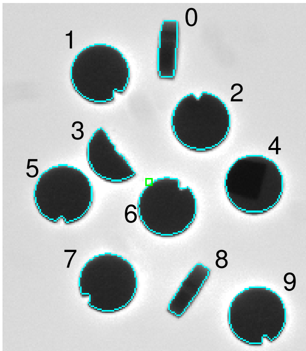


Roi Id	Object Id	Contour Length
Rectangle1_1	0	226.267
Rectangle1_2	0	238.208
Rectangle1_3	0	264.291
Rectangle1_4	0	209.296

Figure 1.6: The length of the contour.

Shape

ActivFeatureCalc provides several features which describe the shape of the blob. The features `Compactness`, `Circularity`, `Anisometry`, and `Bulkiness` have in common that they describe how similar the blob is to a circle. The feature `Convexity` describes how convex a blob is. Figure 1.7 shows the resulting values for an example image of pills.



Object Id	Area	Compactness	Contour Length
8	408.000	1.638	91.640
0	421.000	1.536	90.142
3	623.000	1.350	102.811
6	1091.000	1.158	125.983
9	1083.000	1.145	124.811
7	1094.000	1.144	125.397
5	1098.000	1.138	125.296
1	1104.000	1.133	125.397
2	1104.000	1.132	125.296
4	1114.000	1.053	121.397

Object Id	Area	Circularity
1	1104.000	1.000
2	1104.000	1.000
4	1114.000	1.000
5	1098.000	1.000
6	1091.000	1.000
7	1094.000	1.000
9	1083.000	1.000
3	623.000	0.526
8	408.000	0.406
0	421.000	0.394

Object Id	Major Radius	Minor Radius	Anisometry
8	20.373	6.503	3.133
0	20.596	6.637	3.103
3	19.272	10.907	1.767
9	18.904	18.322	1.032
5	18.988	18.468	1.028
7	18.943	18.461	1.026
2	19.014	18.541	1.025
1	19.008	18.557	1.024
6	18.889	18.462	1.023
4	18.906	18.755	1.008

Object Id	Area	Major Radius	Minor Radius	Bulkiness
3	623.000	19.272	10.907	1.060
0	421.000	20.596	6.637	1.020
8	408.000	20.373	6.503	1.020
9	1083.000	18.904	18.322	1.005
1	1104.000	19.008	18.557	1.004
6	1091.000	18.889	18.462	1.004
7	1094.000	18.943	18.461	1.004
2	1104.000	19.014	18.541	1.003
5	1098.000	18.988	18.468	1.003
4	1114.000	18.906	18.755	1.000

Object Id	Area	Convexity	Area Convex
4	1114.000	0.988	1128.000
5	1098.000	0.976	1125.000
1	1104.000	0.974	1134.000
2	1104.000	0.974	1133.000
9	1083.000	0.970	1117.000
7	1094.000	0.968	1130.000
6	1091.000	0.965	1131.000
0	421.000	0.963	437.000
3	623.000	0.960	649.000
8	408.000	0.947	431.000

Figure 1.7: Calculating different shape features.

The `Compactness` of a blob is calculated as

$$\texttt{Compactness} = \frac{\texttt{Contour Length}^2}{4\pi\texttt{Area}}$$

For a perfect circle it becomes `1`, while getting $>$ `1` for other. In the example, pill no. 4 is most similar to a circle as it has no "dent", the two pills lying on their edge (no. 0 and 8) are the most dissimilar.

The `Circularity` of a blob is calculated as

$$\texttt{Circularity} = \frac{\texttt{Area}}{R_{max}^2 \pi}$$

with R_{max} being the largest distance from the center of mass to the contour (not to be confused with `Major Radius`!). Thus, for a perfect circle it becomes `1`, while getting $<$ `1` for other shapes. In the example, all pills except no. 0, 3, and 8 have a value of `1`. Because only the largest distance to the contour is examined, the small "dents" do not influence the result in this example.

The `Anisometry` of a blob is calculated as

$$\texttt{Anisometry} = \frac{\texttt{Major Radius}}{\texttt{Minor Radius}}$$

It describes how "elongated" a blob is. For a perfect circle it becomes 1, while getting > 1 for other shapes; the more "elongated" a blob is the larger its `Anisometry`. In the example, the blobs are ordered similarly to the feature `Compactness`.

The `Bulkiness` of a blob is calculated as

$$\texttt{Bulkiness} = \frac{\pi \cdot \texttt{Major Radius} \cdot \texttt{Minor Radius}}{\texttt{Area}}$$

It describes how much the blob "bulges". For a perfect circle or ellipse it becomes 1, while getting > 1 for other shapes. In the example, the blobs are ordered similarly to before, however without large difference, as none of the blobs "bulges".

The `Convexity` of a blob is calculated as

$$\texttt{Convexity} = \frac{\texttt{Area}}{\texttt{Area Convex}}$$

It describes how much the blob differs from its convex hull. For a perfectly convex shape, e.g., a circle or polygon, it becomes 1, while getting < 1 for concave shapes or blobs with holes. In the example, pill no. 4 is the most convex, the "dents" in the pills no. 1, 2, 5, 6, 7, and 9 show up as concavities.

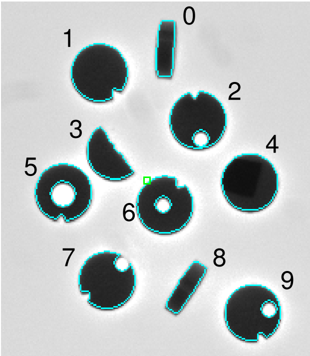
In figure 1.8, some of the pills have holes, which is signalled by the feature `Number of Holes`. Note that pill no. 7 has no hole but an indentation. In the following, the effect of holes on the different shape features is described.

The `Compactness` of a blob increases with holes as its area decreases. Thus, pills no. 2, 5, 6, and 8 have a significantly larger compactness in comparison with figure 1.7 on page 7; pill no. 7 has no hole, but a new concavity, thus the contour length is increased as well. The position of the hole has no influence.

The `Circularity` of a blob decreases with holes as its area decreases. Pill no. 7 shows the same decrease as the others, as holes and concavities have the same influence on the `Circularity`. The position of the hole has no influence.

The `Anisometry` of a blob is only influenced by holes if they affect the features `Minor Radius` and `Major Radius` in a different way. This is the case for pills no. 7 and 2; their `Minor Radius` decreases significantly, while the `Major Radius` remains almost constant.

The `Bulkiness` is affected more by a hole than the `Anisometry`, as it depends not only on `Minor Radius` and `Major Radius` but also on the blob area which decreases with each hole. Another difference is that the influence of a hole is larger if it affects the features `Minor Radius` and `Major Radius` in a similar way. Therefore, pills no. 5 and 6 are affected most because the hole is in the middle, leading to an increase both of `Minor Radius` and of `Major Radius`.



Object Id	Area	Compactness	Contour Length
8	408.000	1.638	91.640
0	421.000	1.536	90.142
7	1027.000	1.516	139.882
5	917.000	1.362	125.296
3	623.000	1.350	102.811
6	1023.000	1.235	125.983
9	1015.000	1.221	124.811
2	1036.000	1.206	125.296
1	1104.000	1.133	125.397
4	1114.000	1.053	121.397

Object Id	Area	Circularity
1	1104.000	1.000
4	1114.000	1.000
6	1023.000	0.958
9	1015.000	0.950
2	1036.000	0.903
7	1027.000	0.903
5	917.000	0.859
3	623.000	0.526
8	408.000	0.406
0	421.000	0.394

Object Id	Major Radius	Minor Radius	Anisometry
8	20.373	6.503	3.133
0	20.596	6.637	3.103
3	19.272	10.907	1.767
7	19.505	17.411	1.120
2	19.591	18.029	1.087
5	20.504	19.886	1.031
1	19.008	18.557	1.024
6	19.460	19.027	1.023
9	18.957	18.524	1.023
4	18.906	18.755	1.008

Object Id	Number of Holes
2	1
5	1
6	1
9	1
0	0
1	0
3	0
4	0
7	0
8	0

Object Id	Area	Major Radius	Minor Radius	Bulkiness
5	917.000	20.504	19.886	1.397
6	1023.000	19.460	19.027	1.137
9	1015.000	18.957	18.524	1.087
2	1036.000	19.591	18.029	1.071
3	623.000	19.272	10.907	1.060
7	1027.000	19.505	17.411	1.039
0	421.000	20.596	6.637	1.020
8	408.000	20.373	6.503	1.020
1	1104.000	19.008	18.557	1.004
4	1114.000	18.906	18.755	1.000

Object Id	Area	Convexity	Area Convex
4	1114.000	0.988	1128.000
1	1104.000	0.974	1134.000
0	421.000	0.963	437.000
3	623.000	0.960	649.000
8	408.000	0.947	431.000
2	1036.000	0.914	1133.000
7	1027.000	0.910	1128.000
9	1015.000	0.909	1117.000
6	1023.000	0.905	1131.000
5	917.000	0.815	1125.000

Figure 1.8: How holes affect the shape features.

The `Convexity` of a blob decreases with holes as with concavities.

Figure 1.9 shows how an irregular contour affects the shape features. In the example, this was provoked by using a low threshold for the blob extraction (compare with figure 1.7 on page 7). The blobs are ordered according to their `Anisometry`.

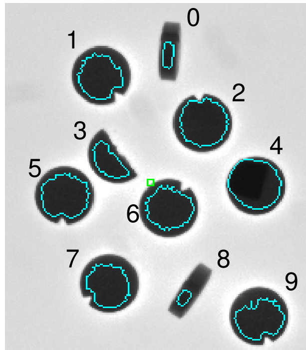
The `Compactness` increases quadratically with the length of its contour, therefore especially pills no. 9 and 6 show a marked increase; as a consequence, the “bad” pills (no. 0, 3, and 8) cannot be distinguished by this feature anymore.

The `Convexity` decreases as the irregular contour forms concavities. “Good” and “bad” pills cannot be distinguished by this feature anymore.

The `Anisometry` rises for most pills, but the “bad” pills still show significantly higher values.

The `Bulkiness` increases for most pills as the irregular contour forms “bulges”. “Good” and “bad” pills cannot be distinguished by this feature anymore.

The `Circularity` is affected most by the irregular contour. Only pill no. 4 still appears as being circular. “Good” and “bad” pills cannot be distinguished by this feature anymore.



Object Id	Compactness	Convexity	Anisometry	Bulkiness	Circularity
0	1.265	0.952	2.267	1.010	0.578
3	1.456	0.922	1.980	1.057	0.503
8	1.080	0.944	1.587	1.016	0.833
9	1.854	0.890	1.316	1.037	0.761
7	1.404	0.925	1.143	1.012	0.812
6	1.609	0.913	1.142	1.012	0.887
4	1.097	0.974	1.126	1.002	0.949
5	1.381	0.931	1.111	1.012	0.872
1	1.446	0.914	1.056	1.017	0.865
2	1.260	0.939	1.018	1.005	0.887

Figure 1.9: How irregular contours affect the shape features.

Moments

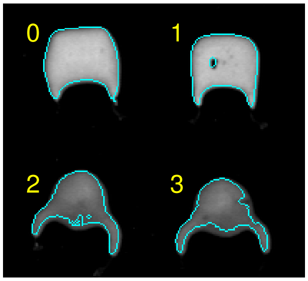
ActivFeatureCalc provides various features based on moments: The normalized 2nd moments `2nd Moments 02` and `2nd Moments 20`, the normalized 3rd moments `3rd Moments 30`, `3rd Moments 21`, `3rd Moments 12`, and `3rd Moments 03`, and the more complex moments `2nd Moments Phi 1`, `2nd Moments Phi 2`, `Central Moments Psi 1`, `Central Moments Psi 2`, `Central Moments Psi 3`, and `Central Moments Psi 4`. These features can be used in classification applications. The mathematical background is given in appendix A on page 47.

Gray Values

The features described so far are based on spatial information about the blob, i.e., only the (relative) position of the pixels of a blob counts, not their gray values. In contrast, this section and the following one describe features which evaluate the distribution of the gray values occurring in the blob.

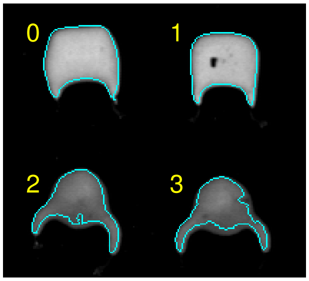
ActivFeatureCalc provides 6 basic gray value features: The smallest and the largest occurring gray value (`Min`, `Max`) and the corresponding gray value `Range`, the `Mean` gray value and the `Deviation` from it (see appendix A.5 on page 50 for the mathematical background), and the so-called `Median` which we will focus on below. In figure 1.10, these features are calculated for two types of capacitors. All capacitors have an identical smallest gray value because this value was used as threshold for the blob extraction. As you can see, the two capacitor types (0 & 1 vs. 2 & 3) can be easily distinguished by their mean gray value; furthermore, capacitors 0 and 1 have a larger range and deviation of occurring gray values.

a)



Object Id	Mean	Deviation	Min	Max	Range	Median
0	164.847	34.211	70.000	211.000	141.000	176.000
1	163.617	30.489	70.000	202.000	132.000	175.000
2	95.151	14.379	70.000	136.000	66.000	94.000
3	93.538	14.529	70.000	134.000	64.000	92.000

b)



Object Id	Mean	Deviation	Min	Max	Range	Median
0	164.847	34.211	70.000	211.000	141.000	176.000
1	162.477	32.886	0.000	202.000	202.000	175.000
2	95.080	14.426	67.000	136.000	69.000	94.000
3	93.538	14.529	70.000	134.000	64.000	92.000

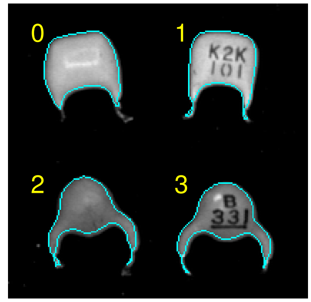
Figure 1.10: Basic gray value features; (a) with hole, (b) without hole.

In figure 1.10b, the hole corresponding to the dark "stain" on capacitor no. 1 was closed, resulting in a clear change in the feature `Min`. Furthermore, the feature `Mean` decreases by more than one gray value, even though only a small number of pixels have been added. This shows that the feature `Mean` is sensitive to small disturbances if their gray value differs significantly because each pixel contributes equally. In contrast, the `Median` is calculated by sorting the gray values of all pixels in ascending order and then determining the gray value of the element in the exact middle of the list. As you can see in figure 1.10, the `Median` stays constant with or without the hole.

Texture

ActivFeatureCalc provides six gray level features describing the *texture* of a blob. Figure 1.11 shows their values together with the basic gray level features for two types of capacitors, each one once with print and once without. For the mathematical background please refer to appendix A on page 47.

The feature `Entropy` is a measure for the "disorder" of the gray values in the blob. `Entropy` is high if many different gray values occur with a similar frequency; it becomes `0` if only one gray value occurs and `8` if all (256) gray values occur with the same frequency.In figure 1.11, it



Object Id	Energy	Correlation	Homogenity	Contrast	Mean	Deviation	Min	Max	Range	Median	Entropy	Anisotropy
0	0.008	0.916	0.405	14.658	164.653	34.585	58.000	238.000	180.000	174.000	6.892	-0.547
1	0.004	0.772	0.283	49.736	165.522	37.691	63.000	227.000	164.000	178.000	6.919	-0.550
2	0.012	0.795	0.499	8.609	101.460	16.277	61.000	202.000	141.000	100.000	5.967	-0.491
3	0.005	0.759	0.329	30.067	99.238	30.404	9.000	233.000	224.000	101.000	6.715	-0.515

Figure 1.11: Gray value features describing the texture.

is lowest for capacitor no. 2, which is quite homogeneous; its `Range` and `Deviation` are low as well.

The feature `Anisotropy`, which lies between `-1` and `0`, describes how much of the disorder stems from the darker half of the blob's pixels. It becomes `-0.5` if dark and light pixels are equally “disorderly”; values between `-0.5` and `0` signal that the lighter part of the blob is more homogeneous, values smaller than `-0.5` that the dark part is more homogeneous. If the `Entropy` is `0`, the `Anisotropy` is `0` as well.

In the features described above, the pixels were examined one by one. The following features examine how frequently two gray values occur next to each other, the neighborhood being evaluated horizontally, vertically, and along the two diagonals.The feature `Energy` is high if a few gray value combinations dominate. It becomes `1` if there is only one combination, i.e., if the gray value is constant over the blob; the `Energy` of a perfect chessboard pattern is `0.5`. In figure 1.11, capacitor no. 2 has the largest `Energy` as it has the most homogeneous gray value distribution.

The feature `Homogenity` is large if the absolute gray value differences between neighboring pixels are small. It becomes `1` for blobs with a constant gray value and `0.5` if the average gray value difference is `1`, which is the case for capacitor no. 2.

In contrast, the feature `Contrast` increases quadratically with the absolute gray value differences between neighboring pixels, becoming `0` for blobs with a constant gray value. For figure 1.11, the illumination has been chosen such that the capacitors of the same type have a similar `Mean` gray value with or without print; however, they can be easily distinguished by looking at their `Contrast`.

The feature Correlation is a measure of the homogeneity of all neighborhood relations, with values lying between -1 and 1. A large value signals that large parts of the blob have an identical gray value (each); in figure 1.11 for example, this is the case for capacitor no. 0. A negative value signals that pixels have neighbors with a very different gray value. For a chessboard pattern the Correlation becomes 0, because the (negative) values for the horizontal and vertical neighbors and the (positive) values for the diagonal neighbors “cancel out”.

Using Gray Values for the Equivalent Ellipse

In the sections above, the equivalent ellipse was determined from the blob region alone, i.e., without using the gray values. This may lead to problems in the case of small objects like the balls in figure 1.12: When using a high threshold only few pixels are extracted (see figure 1.12a); a single pixel more or less can thus influence the calculation significantly and lead to inaccurate results. By using a lower threshold as in figure 1.12b the calculations get more stable, however the extent of the equivalent ellipse is now larger than desired.

The solution is to include the gray values when calculating the center of gravity and the equivalent ellipse. The corresponding features are called Gray Center Column, Gray Center Row, Gray Orientation, Gray Major Radius, and Gray Minor Radius. The principal idea is that the contribution of a pixel is weighted by its gray value, i.e., bright pixels influence the result more than dark pixels (for the mathematical background see appendix A.4 on page 49). As you can see in figure 1.12c, the calculated ellipse fit the balls better than in figure 1.12b.

Note that the feature Gray Area was intentionally omitted in the example because it is not a more accurate version of Area but something completely different: The Gray Area is calculated as the sum over all gray values in the blob; it can be interpreted as the gray value volume of the blob.

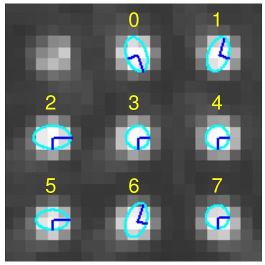
1.1.2 Converting Features to Other Units

You can convert features representing spatial information, i.e., the position and size and contour length, from pixels into other units if you calibrated your vision system using ActivGeoCalib or AVTViewCalibration (see the User’s Manual for ActivGeoCalib and section 3.1 on page 24 for more information about these tools).

1.1.3 ActivFeatureCalc and ActivAlignment

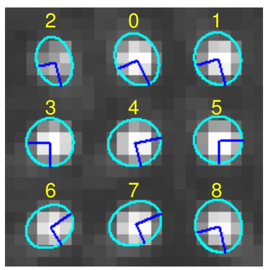
Using ActivAlignment you can align the regions of interest (ROIs) of ActivBlobFinder/ AFeature to a certain part in the image. The main reason for aligning an ROI for blob extraction is to assure that all objects to be extracted and analyzed lie inside the ROI even if the inspected part moves. Most of the features are not influenced by the position or orientation of a blob; the

a)



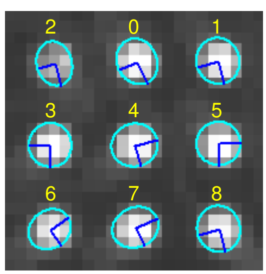
Object	Area	Center Row	Center Col	Orientation	Major Rad	Minor Rad
0	5.000	158.200	285.400	-71.565	1.549	0.894
1	5.000	158.200	292.600	71.565	1.549	0.894
2	6.000	165.500	278.000	0.000	1.633	1.000
3	4.000	165.500	285.500	0.000	1.000	1.000
4	4.000	165.500	292.500	0.000	1.000	1.000
5	4.000	172.750	278.000	0.000	1.414	0.866
6	5.000	172.800	285.400	71.565	1.549	0.894
7	4.000	172.500	292.500	0.000	1.000	1.000

b)



Object	Area	Center Row	Center Col	Orientation	Major Rad	Minor Rad
0	14.000	158.214	285.357	114.358	2.371	1.843
1	15.000	158.133	292.467	104.036	2.309	2.031
2	11.000	158.364	278.091	-74.929	2.173	1.534
3	14.000	165.500	277.714	90.000	2.104	2.060
4	15.000	165.533	285.133	-165.964	2.309	2.031
5	14.000	165.286	292.500	-180.000	2.104	2.060
6	12.000	172.917	277.667	-145.278	2.182	1.761
7	14.000	172.643	285.214	-155.642	2.371	1.843
8	15.000	172.867	292.533	-75.964	2.309	2.031

c)



Object	Gray Center Row	Gray Center Col	Gray Orient	Gray Major Rad	Gray Minor Rad
0	158.163	285.290	-64.062	2.060	1.747
1	158.118	292.529	-68.035	2.034	1.890
2	158.354	278.137	-81.841	1.970	1.551
3	165.498	277.789	72.006	1.925	1.878
4	165.519	285.175	18.896	2.052	1.882
5	165.364	292.542	-12.667	1.936	1.890
6	172.905	277.775	32.097	1.953	1.658
7	172.744	285.210	24.227	2.083	1.738
8	172.876	292.586	-68.069	2.041	1.890

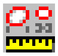
Figure 1.12: Comparing standard and gray value moments: (a) standard ellipse, high threshold; (b) standard ellipse, low threshold; c) gray value ellipse, low threshold.

exceptions are of course the position and orientation of the blob themselves. ActivAlignment offers to transform these features back into the so-called reference image (see the User's Manual for ActivAlignment for more information). This mechanism is useful if you want to inspect the position or orientation of blobs relative to a fixed point in the image.

! Please note that **the features `Height` and `Width` cannot be transformed back into the reference image!**

1.2 The Sub-Tools of ActivFeatureCalc

Besides its *master tool*, ActivFeatureCalc provides 4 *support tools*. In figure 1.13 on page 16 they are depicted together with other ActivVisionTools that you will use in a typical ActivFeatureCalc application.



`AVTFeatureCalc` is the *master tool* of ActivFeatureCalc. Note that this ActiveX control does not have a graphical user interface; thus, it is represented by its icon at design time and invisible at run time. If you forget to add `AVTFeatureCalc` to the form and only add the support tools, they are disabled.

`AVTFeatureCalcBasic` is a *support tool* of ActivFeatureCalc. It allows you to select which basic features are to be calculated.

`AVTFeatureCalcShape` is a *support tool* of ActivFeatureCalc. It allows you to select which shape features are to be calculated.

`AVTFeatureCalcMoments` is a *support tool* of ActivFeatureCalc. It allows you to select which moments are to be calculated.

`AVTFeatureCalcGray` is a *support tool* of ActivFeatureCalc. It allows you to select which gray value features are to be calculated.

How to use the support tools is described in section 2.2 on page 20.

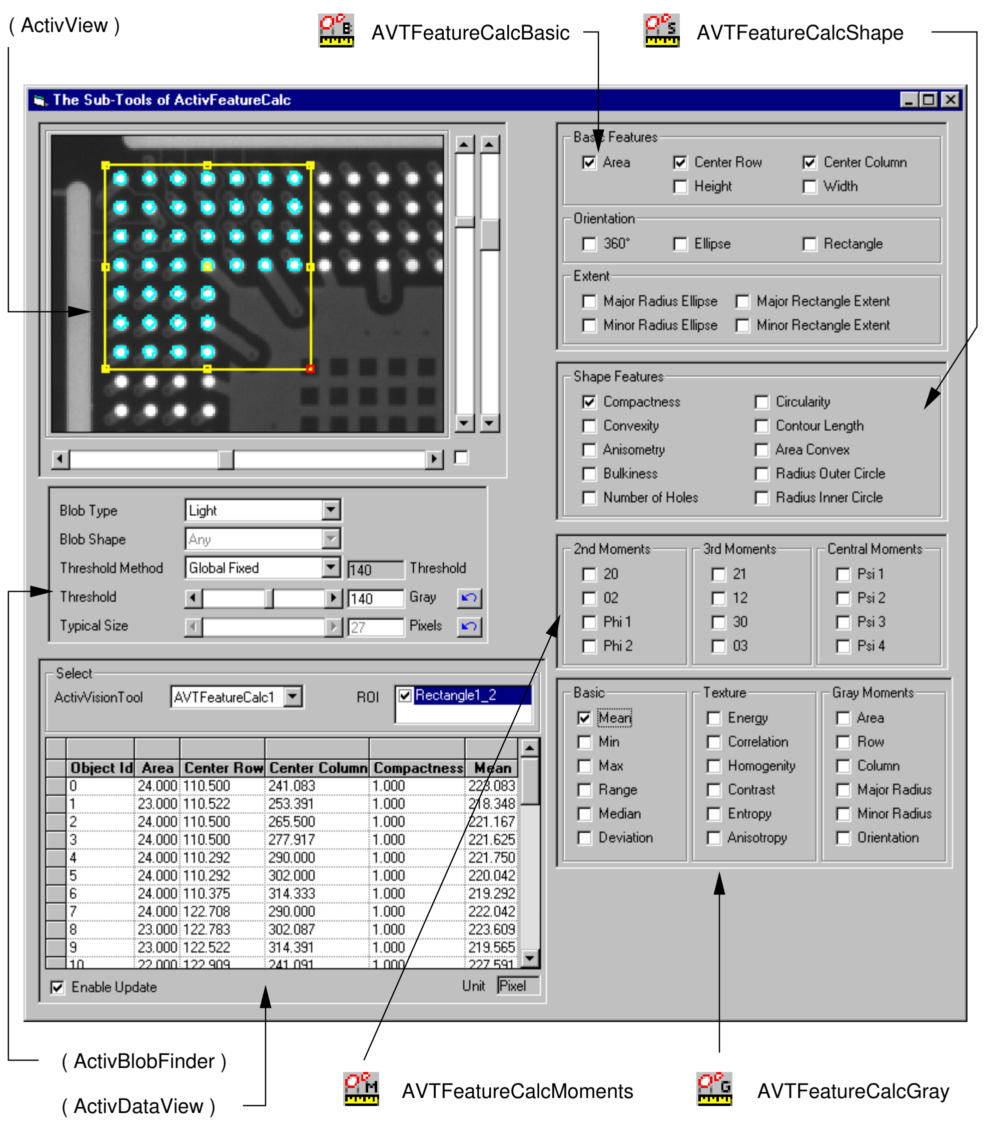
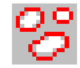


Figure 1.13: The sub-tools of ActivFeatureCalc together with suitable other tools.

Chapter 2

Using ActivFeatureCalc

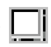
This chapter explains how to select the features you want to be calculated. Before this, it briefly shows how to extract the blobs which form the input for ActivFeatureCalc.

2.1 Extracting Objects Using 

Before calculating blob features, the blobs must be extracted, of course. This section gives a brief overview of how to do this using `AVTBlobFinder`, the *master tool* of ActivBlobFinder, and `AVTViewROI`, which is a *support tool* of ActivView. Please consult the User's Manual for ActivBlobFinder for detailed information.

Visual Basic Example

Preparation for the following example:

- ☐ Open the project `extracting\feature_extracting.vbp`. Alternatively, create a new project and place `AVTView`, `AVTViewROI`, and `AVTBlobFinder` on the form by double-clicking the icons  ,  , and  , respectively, with the left mouse button.
- ☐ Execute the application (`Run` ▷ `Start` or via the corresponding button). Open `AVTViewFG` by clicking into `AVTView` with the right mouse button and selecting `Image Acquisition` in the popup menu. Select the image `bga\bga_01` in the combo box `Input File`.

The following steps are visualized in figure 2.1.

1. First, you have to tell `AVTViewROI` to create an ROI for ActivBlobFinder by selecting the corresponding entry in the combo box `ActivVisionTool`. In this box, all ActivVisionTools are listed that have been placed upon the form. By default, the tools are referenced by the name of the corresponding ActiveX control plus a counter to distinguish between multiple instances of a control on the form. In our example, there is only one item in the combo box, `AVTBlobFinder1`.
2. Next, select the desired shape of the ROI, for example a rectangle.
3. To draw the ROI, move the mouse in the image while keeping the left mouse button pressed. Please experiment at this point with the different shapes.
4. You can now move the ROI by dragging its pick point in the middle. By dragging the outer pick points you modify its shape. Again, please experiment to get familiar with the ROIs.
5. Select the extraction method in the combo box `Threshold Method`, e.g., `'Global Fixed'` to use one global threshold.
6. In the combo box `Blob Type`, select whether the blobs to be extracted are darker or lighter than the background; to extract the balls, select `'Light'`.

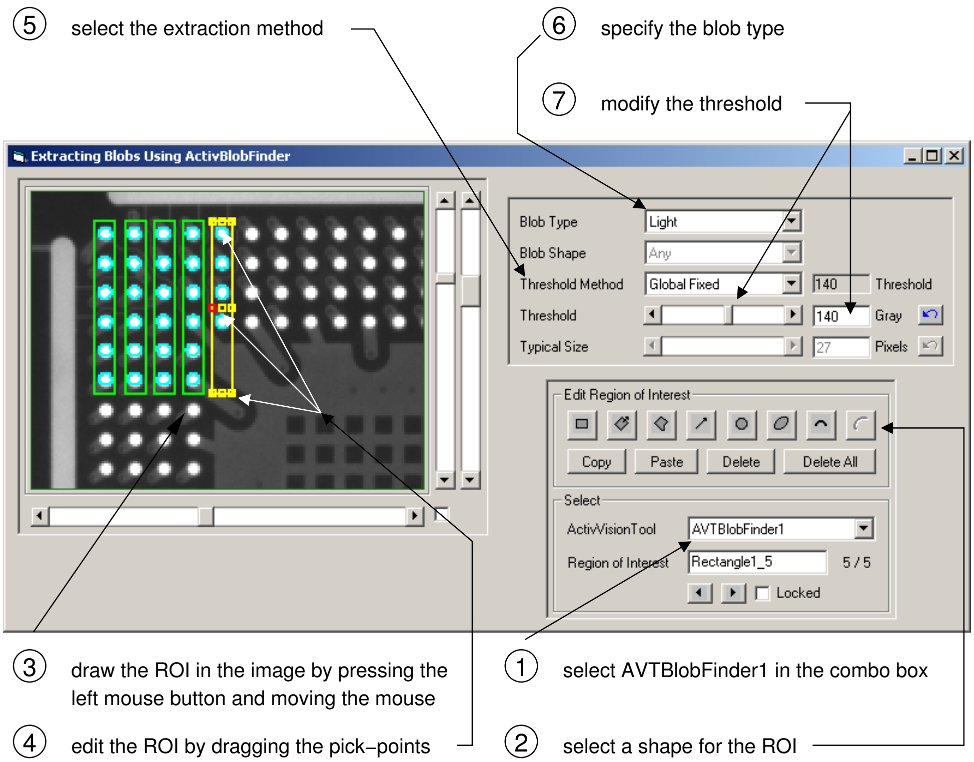


Figure 2.1: Extracting blobs.

⑦ As the default value for the threshold is suited to this image, the blobs corresponding to the balls in the image are already extracted, without any action on your part. Experiment with different thresholds by using the slider `Threshold` or by specifying a value in the text field beside it.

2.2 Selecting Features Using

You can select which features are to be calculated for each extracted blob using the *support tools* of ActivFeatureCalc. `AVTFeatureCalcBasic` contains basic shape features like the `Area` of a blob, `AVTFeatureCalcShape` more complex shape features like the `Compactness` or the `Number of Holes`, `AVTFeatureCalcMoments` higher moments, and `AVTFeatureCalc-Gray` gray value features like `Mean` or `Contrast` and mixed gray value shape features like `Gray Major Radius`.

Visual Basic Example

Preparation for the following example:

- ☐ If you worked on the previous example, you may continue using this project. At design time, add `AVTFeatureCalc`, `AVTFeatureCalcBasic`, and `AVTDataView` to the form by double-clicking , , and with the left mouse button. Note that `AVTFeatureCalc` is only represented by its icon on the form!

  Otherwise, open the project `selecting\feature_selecting.vbp`.
- ☐ Execute the application (`Run` ▷ `Start` or via the corresponding button) and load the image `bga\bga_01`.

! **There are two things to note about** `AVTFeatureCalc` , the master tool of ActivFeatureCalc: First, it does not have a graphical user interface; thus, it is represented by its icon at design time and invisible at run time. If you forget to add it to the form and only add the support tools, they are disabled (and do not calculate any features). Secondly, if you have more than one instance of ActivBlobFinder on the form, you can select to which one `AVTFeatureCalc` is to be connected via `AVTViewConnections` (see the User's Manual for ActivView, section 3.5 on page 36).

The following steps are visualized in figure 2.2.

(1) While experimenting with parameters concerning blob extraction it is useful to switch off the update of results in `AVTDataView` via the corresponding check box!

(2) You can select features to be calculated by checking their box.

(3) At run time, you can open the other sub-tools of ActivFeatureCalc by clicking into `AVT-View` or `AVTBlobFinder` with the right mouse button and selecting the corresponding entry in the popup menu.

(4) Select the ROIs whose results you want to examine in ActivDataView by checking their box. Their results are then displayed in a table, the columns corresponding to the selected features.

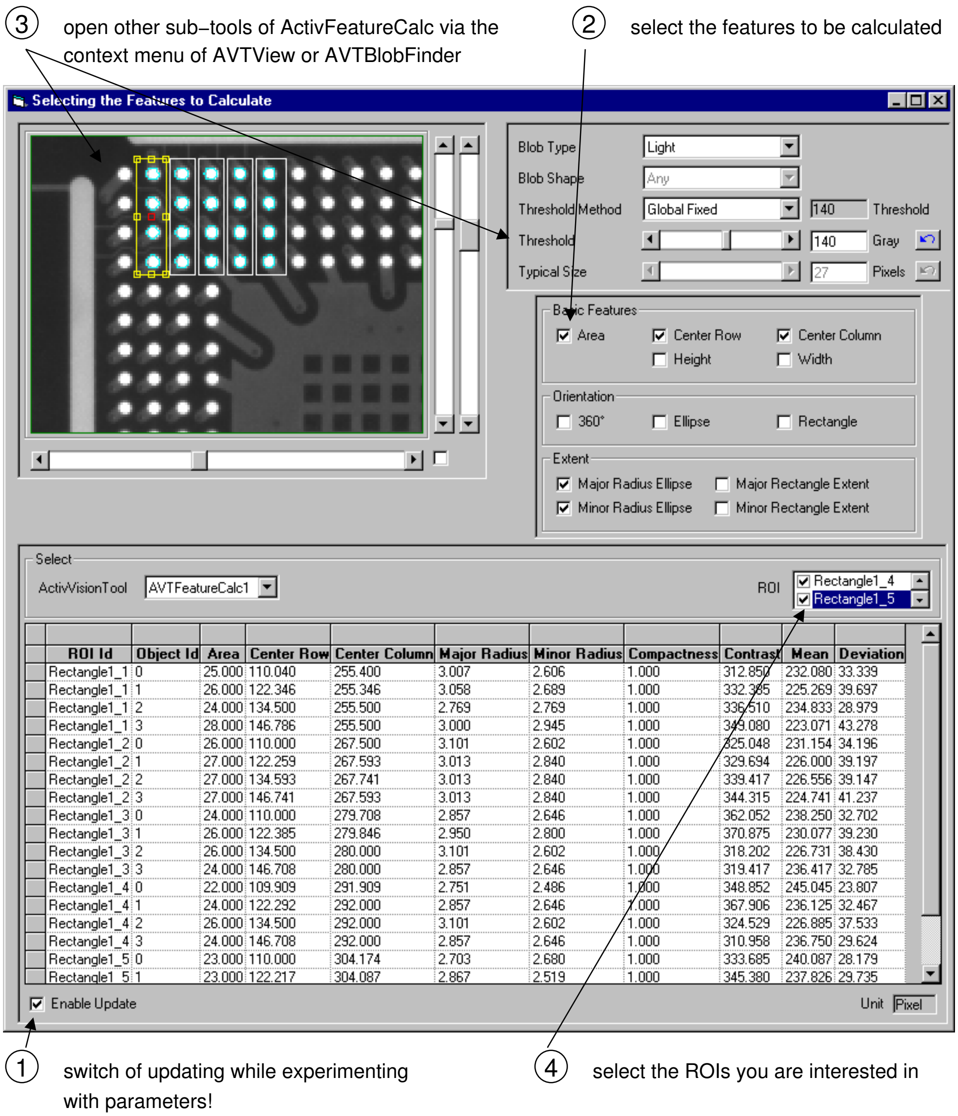


Figure 2.2: Selecting the features which are to be calculated.

You can also display the distribution of the calculated feature values in a histogram using ActivFeatureHistogram, which can be opened by clicking on `AVTView` with the right mouse button and selecting `Feature Histogram` in the appearing context menu..

Chapter 3

Combining ActivFeatureCalc with other ActivVisionTools

While the previous chapter explained how to select the features to be calculated, this chapter focuses on how to further process them by converting them into other units, and how to evaluate and output the results using other ActivVisionTools. How to access results and evaluations via the programming interface is described in chapter 4 on page 31.

In the corresponding Visual Basic projects, the task is to inspect a ball grid array (*BGA*).

3.1 Converting Results to Other Units Using

In section 2.2 on page 20, positions and extents were calculated in image coordinates, i.e., pixels. Using `AVTViewCalibration`, you can convert these features into other units. Note that for a more accurate calibration you should employ ActivGeoCalib (and possibly rectify the image as described in User's Manual for ActivGeoCalib, section 4.2 on page 26).

The main idea behind `AVTViewCalibration` is that the user draws a line in the image and tells ActivVisionTools that the length of this line is in a certain unit. From this information, `AVTViewCalibration` calculates the size of a pixel (i.e., its height as square pixels are assumed) in this unit, which in its turn can be used to convert features from pixels into the new unit. Note that this conversion only works if the measured objects lie in the same plane, i.e., at the same distance from the camera, as the line whose length was specified.

Visual Basic Example

Preparation for the following example:

- ☐ If you worked on the example in the previous chapter, you may continue using this project. At design time, add `AVTViewCalibration` to the form by double-clicking with the left mouse button. You may remove `AVTFeatureCalcBasic` and `AVTDataView`.

  Otherwise, open the project `units\feature_units.vbp`.
- ☐ Execute the application (`Run ▷ Start` or via the corresponding button) and load the image `bga\bga_01`.

The following steps are visualized in figure 3.1 (not shown: `AVTBlobFinder`).

① You create the line of known length using `AVTViewROI`. First, select `AVTViewCalibration1` in the combo box `ActivVisionTool`.

② To start creating the line, click .

③ To draw the line, move the mouse in the image while keeping the left mouse button pressed.

④ You can modify the line by dragging the pick points; to position it precisely we recommend to zoom the image using the scrollbars of `AVTView`. Place the ROI as shown in the figure; this distance corresponds to `2.7 cm`.

⑤ Now, switch your attention to `AVTViewCalibration`. Select the desired unit (`cm`) in the combo box `Unit`. The labels below denoting the unit will automatically switch to the selected unit.

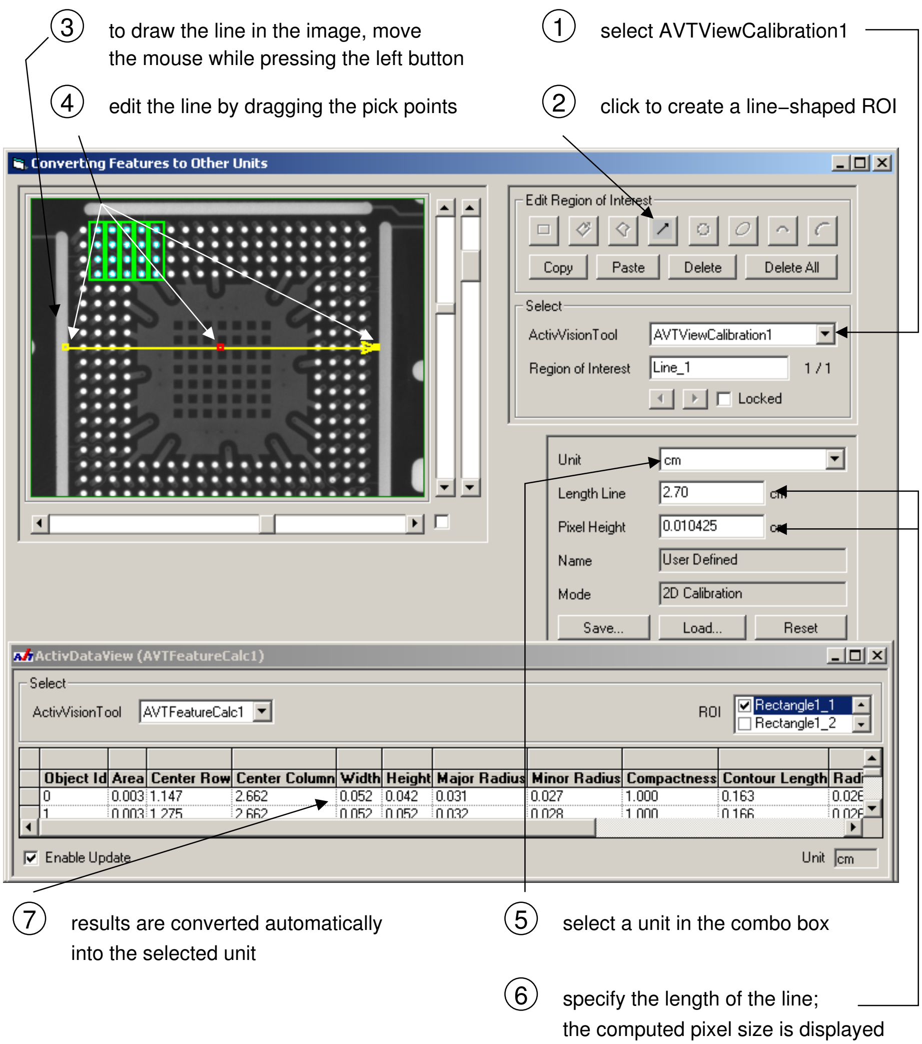


Figure 3.1: Converting measurements into other units.

⑥ Then, specify the length of the line (2.7) in the text box `Length Line` and press `Enter`. `AVTViewCalibration` now calculates the height of a pixel in `mm` and displays it in the text box `Pixel Height`.

⑦ Automatically, all calculated positions and extents are converted into the selected unit.

3.2 Evaluating Results Using

In the former examples, you have employed ActivVisionTools to calculate features for blobs. In the following, we show how to use ActivDecision to evaluate these results by formulating *conditions* the features have to meet in order to be "okay". For a detailed description of ActivDecision please consult the User's Manual for ActivDecision.

In the example task, the extracted balls must be circular (measured by the feature `Compactness`) with a radius of at least `0.25 mm` (measured by the features `Area`, `Major Radius`, resultFeatureMinorEllExtent). Surface disturbances can be detected by analyzing the `Mean` gray value. Note that only a part of the BGA is inspected; each ROI should contain 4 balls.

Visual Basic Example

Preparation for the following example:

☐ If you worked on the previous example, you may continue using this project. At design time, add `AVTDecision` to the form by double-clicking with the left mouse button.

Otherwise, open the project `decisions\feature_decisions.vbp`.

☐ Execute the application and load the image sequence `bga\bga1.seq`.

The following steps are visualized in figure 3.2 (not shown: `AVTView`, `AVTBlobFinder`).

(1) The main functionality of ActivDecision is presented by its *support tools*, which can be opened via clicking on `AVTDecision` with the right mouse button. The *master tool* displays the overall evaluation of the application.

(2) To view the current feature and evaluation results check ☑ `Enable Update` in `AVTDecisionViewResults`.

(3) ActivDecision lets you compare the value of an individual object, ROI, or tool feature with two boundary values, a minimum and a maximum value. You can formulate conditions for features by specifying values in the columns `Min` and `Max` and selecting a comparison mode in the column `Operation`. If you select `None`, the feature is not evaluated.

(4) Those features which meet their condition appear in green, the others in red. If at least one feature is "not okay", the whole object, ROI, or tool is evaluated as "not okay" as well. Analogously, the overall evaluation of application, which is visualized by `AVTDecision`, depends on the tool evaluations.

Figure 3.2 shows suitable conditions for the example task. Step through the image sequence and examine the evaluations; in some of the images, balls are defect or missing.

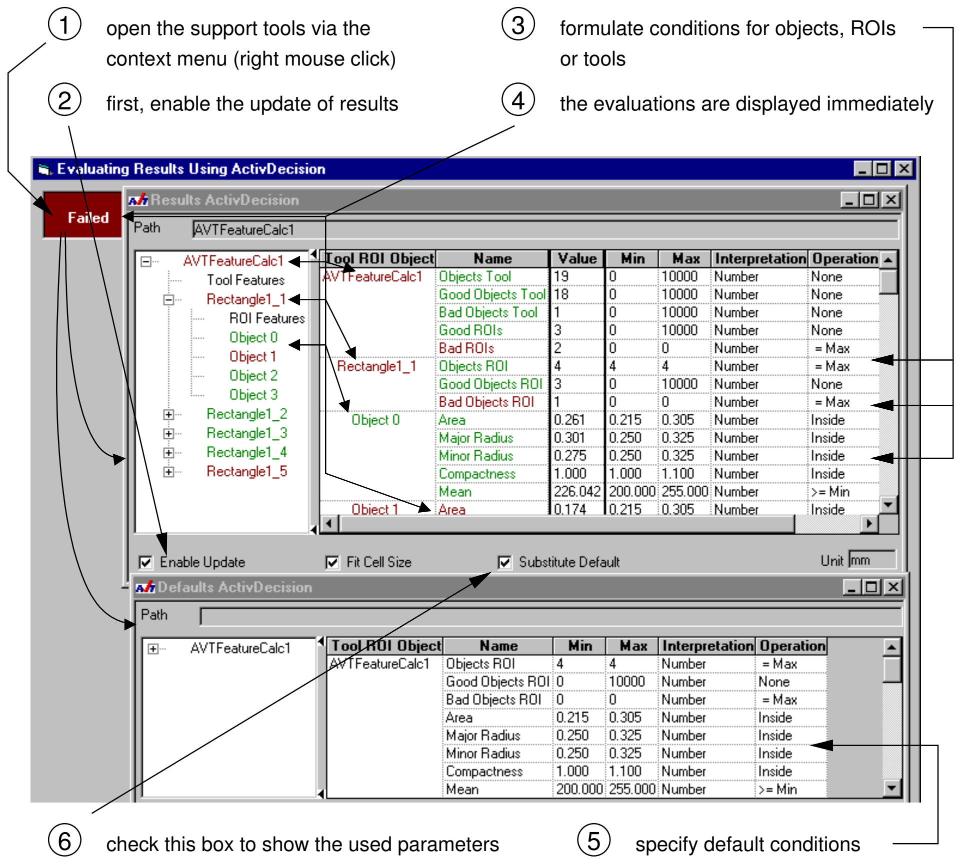


Figure 3.2: Formulating conditions to evaluate results.

(5) If many similar objects are extracted which all should meet the same conditions, you can specify default conditions using `AVTDecisionViewDefaults`. Defaults can be set per tool or per ROI; ROI defaults override tool defaults, and individual conditions override defaults.

(6) If you check ✓ `Substitute Default`, the entries marked `Default` are substituted by their actual content.

3.3 Output of Results Using

Using ActivFile, you can write the results and the evaluations to a log file. How to access results via the programming interface is described in section 4.2 on page 34, how to output them via a serial interface or a digital I/O board in the User's Manual for ActivSerial and the User's Manual for ActivDigitalIO, respectively.

Visual Basic Example

Preparation for the following example:

- ☐ If you worked on the previous example, you may continue using this project. At design time, add `AVTOutputFile` by double-clicking .

  Otherwise, open the project `output\feature_output.vbp`.
- ☐ Execute the application and load the image sequence `bga\bga1.seq`.

The following steps are visualized in figure 3.3 (not shown: `AVTView` and `AVTDecision`).

1. By clicking on `Select`, you can open a file selector box to choose a file name for the log file, which will then appear in the text field beside the button. By pressing `Clear File`, you can clear the content of the selected file.
2. By checking ✓ `Enable Writing` you enable the writing mode.
3. You can open the ActivFile's two dialogs `DialogFileOptions` and `DialogOutput-DataSelect` by clicking `File Options` and `Data Selection`, respectively.
4. In `DialogFileOptions`, you can choose between two file formats: Standard text files (suffix `.txt`) and the so-called *comma-separated values* (suffix `.csv`) which can be used as an input to Microsoft Excel. Furthermore, you can select a delimiter.
5. In the same dialog you can limit the size of the log file in form of the number of *cycles* that are to be recorded. A cycle corresponds to one processing cycle from image input to the evaluation and output of results. If you use this option, ActivFile creates two log files and switches between them, thus assuring that you can always access (at least) the results of the last N cycles, N being the specified number of cycles.
6. By pressing `Estimate`, you can let ActivFile estimate the size of one cycle. Note that you must first select the output data in order to get meaningful results!
7. In the left part of `DialogOutputDataSelect`, you can navigate through the result hierarchy similarly to ActivDecision.

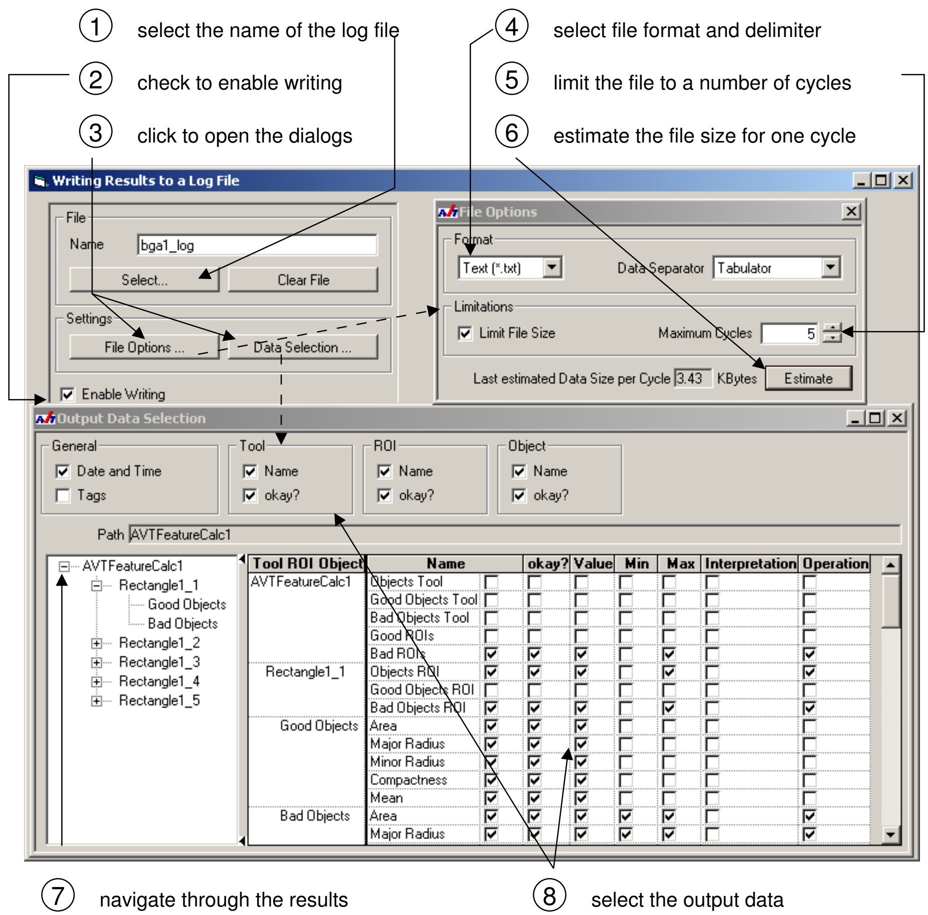


Figure 3.3: Customizing log files.

(8) In the right part of `DialogOutputDataSelect`, choose the output data by checking the corresponding boxes. You may output different items depending on the evaluation of an object. By clicking on the column labels with the right mouse button you can check or uncheck all boxes in the column; similarly, you can check or uncheck whole rows or all rows of a certain tool.

If you now step through the image sequence by clicking `Single` in `AVTViewFG`, the log file is created. Figure 3.4 shows part of an example log file.

```
09/10/04  11:50:29
AVTFeatureCalc1  no
      Bad ROIs  no  2  0   = Max
  Rectangle1_1  no
      Objects ROI  yes  4  4   = Max
      Bad Objects ROI  no  1  0   = Max
    0  yes
      Area          yes  0.260819
      Major Radius  yes  0.300935
      Minor Radius  yes  0.275264
      Compactness   yes  1.000000
      Mean          yes  226.041667
    1  no
      Area          no  0.173879  0.215000  0.305000  Inside
      Major Radius  yes  0.305259  0.250000  0.325000  Inside
      Minor Radius  no  0.211016  0.250000  0.325000  Inside
      Compactness   no  1.219212  1.000000  1.100000  Inside
      Mean          no  192.750000  200.000000  255.000000  >= Min
    2  yes
      Area          yes  0.271686
      Major Radius  yes  0.313434
      Minor Radius  yes  0.271718
      Compactness   yes  1.000000
      Mean          yes  222.800000
    3  yes
      Area          yes  0.239084
      Major Radius  yes  0.299839
      Minor Radius  yes  0.252878
      Compactness   yes  1.000000
      Mean          yes  224.000000
```

Figure 3.4: Part of an example log file.

Chapter 4

Tips & Tricks

This chapter contains additional information that facilitates working with ActivFeatureCalc, e.g., how to customize the appearance of an ActivFeatureCalc application in the two execution modes. Furthermore, it shows how to access the calculated features and the evaluations directly via the programming interface of ActivVisionTools.

ActivFeatureCalc

4.1 Customizing the Two Execution Modes Using

In an ActivVisionTools application you can switch between two execution modes: the *configuration mode* and the *application mode*. The former should be used to setup and configure an application, the latter to run it. ActivView's *support tools* `AVTViewExecute` and `AVTViewConfigExec` allow you to switch between the two modes and to customize the behavior of an ActivVisionTools application in the two execution modes, e.g., display live images only in the *configuration mode* to setup your application, but then switch it off in the *application mode* to speed up the application. A third sub-tool, `AVTViewExecuteSimple`, provides a single button to start/stop the application.

With the help of `AVTViewStatus`, another *support tool* of ActivView, you can inspect the current status of your application.

Visual Basic Example

Preparation for the following example:

- ☐ If you worked on the example in the previous chapter, you may continue using this project. At design time, add `AVTViewExecuteSimple` and `AVTViewStatus` to the form by double-clicking the icons and .

  Otherwise, open the project `usermodes\feature_usermodes.vbp`.
- ☐ Execute the application and load the image sequence `bga\bga1.seq`.

The following steps are visualized in figure 4.1 (not shown: `AVTBlobFinder`).

1. Open `AVTViewExecute` and `AVTViewConfigExec` by clicking on `AVTView` with the right mouse button and selecting `Execution` and `Execution Parameters`.
2. Switch between the two execution modes via `AVTViewExecute`'s combo box `Mode`.
3. To execute one cycle, press `Single`. With the other two buttons you can let the application run continuously and stop it again. By default, `AVTViewExecuteSimple` starts and stops an application; how to change its behavior to a single-step button is described in the User's Manual for ActivView, section 3.4 on page 34.
4. For each of the two execution modes, you can choose what is to be displayed by checking the corresponding boxes in `AVTViewConfigExec`. Please refer to the User's Manual for ActivBlobFinder, section 4.1 on page 34, for more information about adapting the display, e.g., how to choose colors for ROIs and results. Furthermore, you can specify if images can be dragged to the image window and whether ROIs can be modified in the two modes; by default, this is disabled in the *application mode* to prevent you from accidentially moving or deleting an ROI.

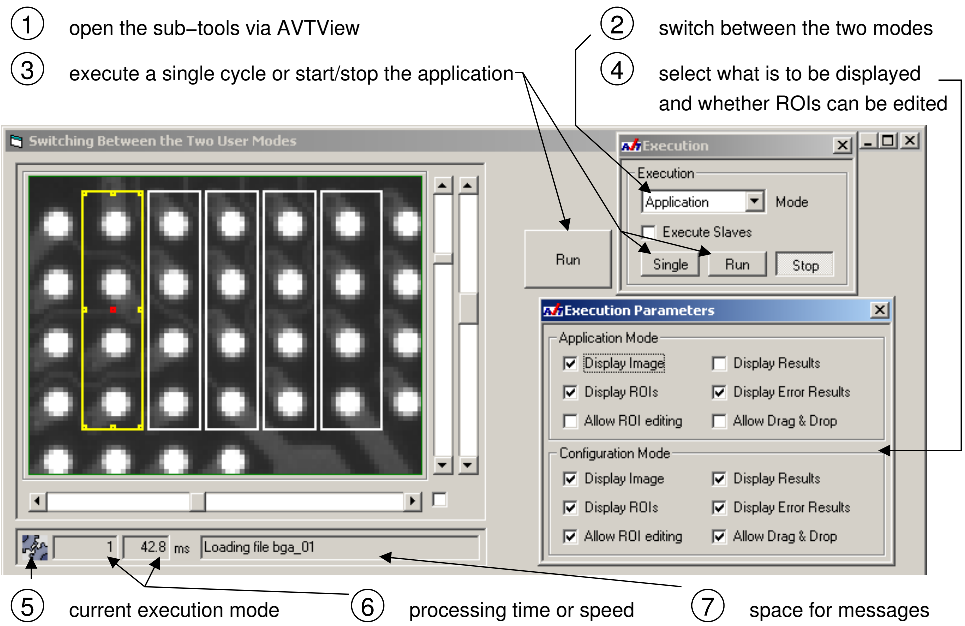


Figure 4.1: Customizing and switching between the two execution modes.

⑤ In AVTViewStatus, an icon indicates the current execution mode of the application. In the mode  , the application does not perform any processing and waits for your interaction. If you start the continuous mode the cogwheels rotate; any interaction on your part is stored in the event queue and processed after the current cycle is finished. If the cursor gets "busy", ActivVisionTools has started a particularly time-consuming operation, e.g., connecting to an image acquisition device. Any interaction on your part is then deferred to the end of this operation.

⑥ AVTViewStatus also shows the number of processed cycles and the time needed for the last processing cycle.

⑦ AVTViewStatus display two types of messages: Informative messages describe, e.g., what the application is doing while it is "busy", while error messages indicate errors that prevent the application from working correctly, e.g., the failure to connect to an image acquisition device. If AVTViewStatus is not added to an application, error messages are displayed in popup dialogs.

More information about AVTViewStatus, e.g., how to modify its appearance, can be found in the User's Manual for ActivView, section 3.3 on page 32.

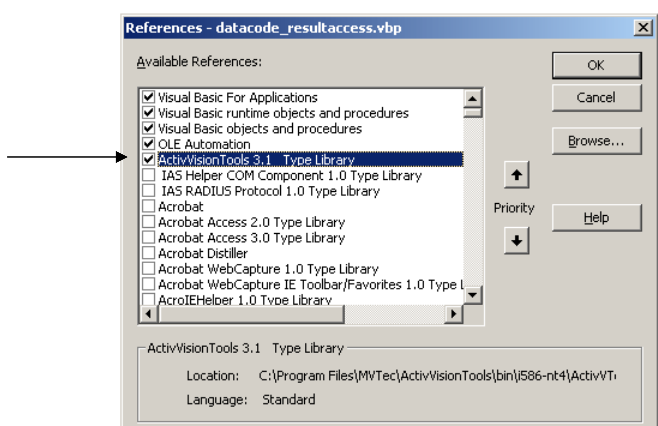
4.2 Accessing Results Via the Programming Interface

The previous chapters and sections showed how to use ActivVisionTools interactively, i.e., via the graphical user interfaces presented by the underlying ActiveX controls. In this mode, you can develop the image processing part of your machine vision application rapidly and easily, without any programming. However, there is more to ActivVisionTools than the graphical user interfaces: Because ActivVisionTools comes as a set of ActiveX controls, it provides you with an open programming interface, thereby offering full flexibility.

In this section, we show how to access the blob features and evaluation results via the programming interface. With this, you can, e.g., realize an application-specific graphical user interface, perform additional processing on the results, or send results to a special output device. Detailed information about the programming interface can be found in the **Reference Manual**.

As in the previous sections, the examples stem from Visual Basic 6.0; if the (ActivVisionTools-specific) code differs in Visual Basic .NET, the corresponding lines are also shown (for the first appearance only). For other .NET languages or C++, please refer to the Advanced User's Guide for ActivVisionTools, section 1.2.3 on page 5 and section 1.3.4 on page 28, respectively. Please note that we assume that readers of this part have at least a basic knowledge of Visual Basic.

! To work with the programming interface, in VB 6.0 you must first **add the ActivVisionTools type library to the project's references** by checking the box labeled `ActivVisionTools Type Library` in the menu dialog `Project` ▷ `References`. In Visual Basic .NET, the reference is added automatically.



4.2.1 Accessing Calculated Features

The principal idea behind accessing the results of an ActivVisionTool is quite simple: When a tool has finished its execution, it raises an event called `Finish`, sending its results as a parameter. If you want to access the results, all you have to do, therefore, is to create a corresponding event procedure which handles the event.

Within the Visual Basic environment, you can create event procedures very easily as shown in figure 4.2: In the header of the form's code window there are two combo boxes. Select the instance of `AVTFeatureCalc` (by default called `AVTFeatureCalc1`) in the left combo box. The right combo box then lists all events available for this object; when you select `Finish`, the event procedure is created automatically. Within this procedure, the measurement results are now accessible via the object variable `atToolResults`.

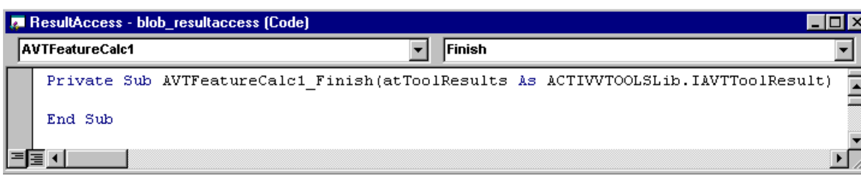


Figure 4.2: Creating a procedure to handle the event `Finish` .

`atToolResults` contains the result data for all ROIs of your instance of `AVTFeatureCalc`. The current number of ROIs can be queried via

```
Dim iNumROIs As Integer
iNumROIs = atToolResults.ROINum
```

In Visual Basic .NET , the event handler has a different signature:

```
Private Sub _
      AxAVTFeatureCalc1_Finish(ByVal sender As Object, _
                               ByVal e As _
                                 AxActivVTools.__AVTFeatureCalc_FinishEvent) _
                               Handles AxAVTFeatureCalc1.Finish
```

A first difference is that tool names start the prefix `Ax`, i.e., `AVTFeatureCalc` becomes `AxAVTFeatureCalc`. The main difference, however, is that the tool results are not directly passed; instead, they are encapsulated in the parameter `e`. From there, they can be extracted with the following lines:

```
Dim atToolResults As AVTToolResult
atToolResults = e.atToolResults
```

To use classes like `ACTIVVTOOLSLib.AVTToolResult` without the namespace `ACTIVVTOOL-`

SLib as in the code above, you must import this namespace by inserting the following line at the very beginning of the code (more information about importing namespaces can be found in the Advanced User's Guide for ActivVisionTools in section 1.2.4.5 on page 12):

```
Imports ACTIVVTOOLSLib
```

The results of a certain ROI can be accessed by specifying its name in a call to the method `ROIResult`, or by specifying its index in a call to the method `ROIResults`. The following code uses the latter method to access the first ROI of `AVTFeatureCalc1`:

```
Dim atROIResult As AVTROIResult

Set atROIResult = atToolResults.ROIResults(0)
```

Now, we can, e.g., query the number of objects extracted in the ROI via

```
Dim iNumObjects As Integer

iNumObjects = atROIResult.ObjectNum
```

Actual results for an object, i.e., the calculated values of features like `Major Extent` or `Area`, can be accessed by specifying the feature of interest and the ID of the object in a call to the method `ObjectValue` of `ACTIVVTOOLSLib.AVTROIResult`. The feature handles are available as methods of the corresponding tool, e.g., `AVTFeatureCalc.FeatureHandleArea` being the handle for the calculated area.

The following code fragment uses another method of `ACTIVVTOOLSLib.AVTROIResult`, `ObjectValues`, which returns the values of all objects for the specified feature in an array, to calculate the mean blob area:

```
Dim handleArea As Integer, i As Integer
Dim vAreaArray As Variant
Dim dSumArea As Double, dMeanArea As Double

handleArea = AVTFeatureCalc1.FeatureHandleArea
vAreaArray = atROIResult.ObjectValues(handleArea)
dSumArea = 0
For i = 0 To iNumObjects - 1
  dSumArea = dSumArea + vAreaArray(i)
Next
dMeanArea = dSumArea / iNumObjects
```

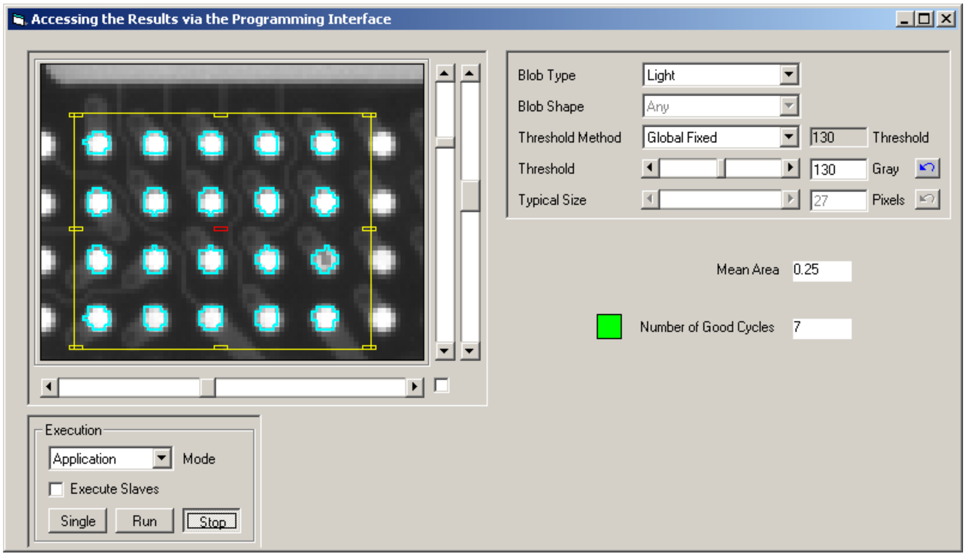


Figure 4.3: Accessing and displaying the calculated features.

A general difference **in Visual Basic .NET** is that instead of the type `Variant` you must use `Object` when accessing multiple values:

```
Dim vAreaArray As Object
```

The ActivVisionTools distribution includes the example Visual Basic project `resultaccess\feature_resultaccess.vbp`, which uses the methods described above to inspect BGAs similarly to the application introduced in the previous chapter. The task is to calculate the mean area of all balls; on contrast to the previous chapter only one ROI is used here (see figure 4.3). The example project is already configured, just start it and click the button `Run` in `AVTViewExecute`.

Besides accessing the calculated features, the project code contains additional functionality which is explained briefly in the following. Note that the code is only shown for Visual Basic 6.0; a Visual Basic .NET application with result access can be found in the directory `examples\dotnet\vb\blob_results`.

First of all, the calculated area is only to be read and displayed if all balls have the correct size and extent:

```
For i = 0 To iNumObjects - 1
  dArea = atROIResult.ObjectValue(handleArea, i)
  dMajorRadius = atROIResult.ObjectValue(handleMajorRadius, i)
  dMinorRadius = atROIResult.ObjectValue(handleMinorRadius, i)
  If dArea >= 0.215 And dArea <= 0.305 And _
    dMajorRadius >= 0.25 And dMajorRadius <= 0.325 And _
    dMinorRadius >= 0.25 And dMinorRadius <= 0.325 Then
    ' sum Area
    dSumArea = dSumArea + dArea
  Else
    TextMeanArea.Caption = "---"
    Call SetAlarm
    Exit Sub
  End If
Next
dMeanArea = dSumArea / iNumObjects
TextMeanArea.Caption = Format(dMeanArea, "Fixed")
```

If the conditions are not met, the function `SetAlarm` stops the application by setting `AVTView`'s property `RunState` to `'False'` and switches the color of the element beside the number of good cycles to red. The function `ClearAlarm` resets the color to green.

```
Private bIsError As Boolean

Private Function SetAlarm()
  AVTView1.RunState = False
  Light.BackColor = vbRed
  bIsError = True
End Function

Private Function ClearAlarm()
  Light.BackColor = vbGreen
  bIsError = False
End Function
```

As a further condition, the correct number of balls must be present.

```
iNumObjects = atROIResult.ObjectNum
If Not (iNumObjects = 5 * 4) Then
  TextMeanArea.Caption = "---"
  Call SetAlarm
  Exit Sub
End If
```

Below the mean area, the number of BGAs which passed the inspection is to be displayed. For this one has to keep in mind that `AVTFeatureCalc` is executed not only when the next image is grabbed but also whenever you modify its ROI (s) or parameters. To distinguish the two cases an event raised by `AVTView` at the start of each execution cycle can be used to set a variable called `bIsNewCycle`:

```
Private bIsNewCycle As Boolean
Private Sub AVTView1_CycleStart()
  bIsNewCycle = True
End Sub
```

Before increasing the counter of good cycles within the handler for `AVTFeatureCalc`'s event `Finish`, this variable is checked (and immediately reset). You can test this behavior by modifying the blob extraction parameters of `AVTBlobFinder` or `AVTBlobFinderProcess`: The new mean area is displayed, while the number of good cycles remains constant.

```
If bIsNewCycle = True Then
  iNumGoodCycles = iNumGoodCycles + 1
  bIsNewCycle = False
  TextNumCycles.Caption = iNumGoodCycles
End If
```

When using the programming interface of ActivVisionTools, you leave the safe world of the graphical user interfaces where all input is checked for validity automatically. In contrast, if you try to access a non-existent object or result via the programming interface, a run-time error is caused which terminates your application! To avoid this, you can use the Visual Basic error handling mechanisms, i.e., set up an error handler which examines any occurring error and reacts in a suitable way. In the example project, if an error is caused by the result access, a dialog with the error description pops up and the function `SetAlarm` is called.

```
Private Sub AVTFeatureCalc1_Finish(atToolResults As _
                                   ACTIVVTOOLSLib.IAVTToolResult)
   ' variable declarations
On Error GoTo ErrorHandler
   ' procedure body
  Exit Sub

ErrorHandler:
  Dim sTitle As String
  If Left(Err.Source, 11) = "ActivVTools" Then
    sTitle = "ActivVisionTools Error"
  Else
    sTitle = "Runtime Error " & CStr(Err.Number)
  End If
  Call MsgBox(Err.Description, vbExclamation, sTitle)
  Call SetAlarm
End Sub
```

To view the effect of the error handler, de-select the feature `Area` in `AVTFeatureCalcBasic`.

By placing the following code at the beginning of `AVTFeatureCalc1_Finish`, the actual result access is restricted to the *application mode*. With this mechanism you can setup the vision part of your application in the configuration mode without having to worry about run-time errors.

```
If Not AVTView1.ExecutionMode = eApplicationMode Then
  TextMeanArea.Caption = "---"
  Exit Sub
End If
```

4.2.2 Accessing Evaluation Results

The evaluation results can be accessed similarly to the measurement results; in fact, they are even stored in the same object. However, to access the evaluation results you now have to wait for ActivDecision to finish, i.e., create the following event procedure:

```
Private Sub AVTDecision1_Finish(atToolResults As Collection)

End Sub
```

!

Note that **you will get a run-time error if you try to access evaluation results before ActivDecision has finished** (e.g., in the handler for `AVTFeatureCalc`'s event `Finish`!

Because ActivDecision can evaluate the results of more than one tool, the event handler provides you with a `Collection` of tool results. The following code fragment searches the collection for the results of `AVTFeatureCalc1` and "stores" them in `atFeatureResult`, or exits if no results are found:

```
Dim atToolResult As AVTToolResult
Dim atFeatureResult As AVTToolResult
Dim bFeatureResultsFound As Boolean

bFeatureResultsFound = False
For Each atToolResult In atToolResults
  If atToolResult.Name = "AVTFeatureCalc1" Then
    Set atFeatureResult = atToolResult
    bFeatureResultsFound = True
  End If
Next
If bFeatureResultsFound = False Then
  Exit Sub
End If
```

In Visual Basic .NET , the event procedure has the following signature:

```
Private Sub AxAVTDecision1_Finish(ByVal sender As System.Object, _
                                  ByVal e As _
                                    AxActivVTools.__AVTDecision_FinishEvent) _
                                  Handles AxAVTDecision1.Finish
```

Again, the tool results are encapsulated in the parameter `e`. They can be extracted as follows; note the use of `VBA.Collection` instead of `Collection`!

```
Dim atToolResults As VBA.Collection
atToolResults = e.atToolResults
```

As already remarked in the previous section, tool names are prefixed with `Ax`, thus you must

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search for the results of AxAVTFeatureCalc1:

```
If atToolResult.name = "AxAVTFeatureCalc1" Then
```

You can query the overall evaluations at different levels, tool, ROI, or object:

```
Dim atROIResult As AVTROIResult
Dim bToolIsOK As Boolean, bROIIsOK As Boolean, bObjIsOK As Boolean

Set atROIResult = atFeatureResult.ROIResults(0)

bToolIsOK = atFeatureResult.Evaluation
bROIIsOK = atROIResult.Evaluation
bObjIsOK = atROIResult.ObjEvaluation(0)
```

Furthermore, you can access the evaluation of individual features like the measured area of the blob with the ID 0, but also of tool features (e.g., the evaluation of the number of "bad" ROIs) or of ROI features (e.g., the evaluation of the number of objects) via the corresponding feature handle. In contrast to object features, the handles for tool and ROI features are available as properties of ACTIVVTOOLSLib.AVTToolResult.

```
Dim handleArea As Integer, handleBadROIs As Integer
Dim handleObjectsInROI As Integer
Dim bAreaIsOK As Boolean, bBadROIsIsOK As Boolean
Dim bObjectsInROIIsOK As Boolean

Debug.Print "Object 0 OK? " & bObjIsOK

handleArea = AVTFeatureCalc1.FeatureHandleArea
handleBadROIs = atFeatureResult.FeatureHandleBadROIs
handleObjectsInROI = atFeatureResult.FeatureHandleObjectsROI

bAreaIsOK = atROIResult.ObjFeatureEvaluation(handleArea, 0)
bBadROIsIsOK = atFeatureResult.FeatureEvaluation(handleBadROIs)
bObjectsInROIIsOK = atROIResult.FeatureEvaluation(handleObjectsInROI)
```

The ActivVisionTools distribution includes the example Visual Basic project evalaccess\feature_evalaccess.vbp, which uses these methods to extend the application described in the previous section. Now, ActivDecision is used to check the extent of the extracted balls as described in section 3.2 on page 26. The task is to stop the application in case the overall evaluation shows an error and to display the cause of the error (see figure 4.4). The example project is already configured, just start it and click the button Run in AVTViewExecute.

Besides accessing the evaluation results, the project code contains additional functionality which is explained briefly in the following (again only for Visual Basic 6.0!). First of all, the main If - Then - Else clause around the display of calculated features now tests the overall evaluation

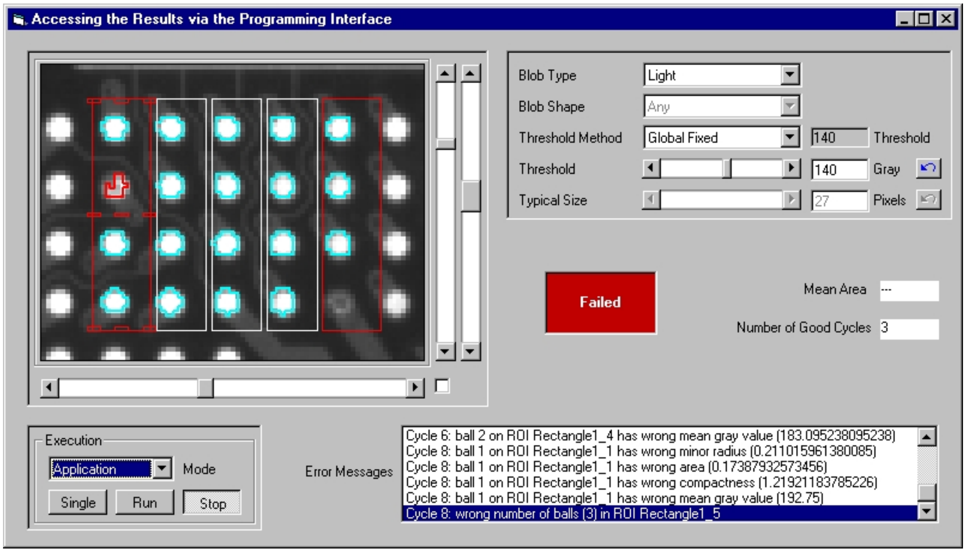

Figure 4.4: Accessing and displaying the evaluation results.

of AVTFeatureCalc1:

```
If atFeatureResult.Evaluation = True Then
  ' access and display the mean area
Else
  ' examine cause of error more closely
End If
```

First, the program checks whether the application contains 5 ROIs. Otherwise, the application is stopped and an error message is displayed. Test this behavior by creating an additional ROI.

```
iNumROI = atFeatureResult.ROINum
If Not iNumROI = 5 Then
  TextMeanArea.Caption = "---"
  sErrMsg = "Cycle " & iNumCycles & ": Corrupt application!"
  Call DisplayMessage(sErrMsg)
  ' evaluation of Activfeature corrupt -> exit
  Call SetAlarm
  Exit Sub
End If
```

If the overall evaluation of `AVTFeatureCalc1` is “not okay”, the cause of error is investigated by checking the evaluations in a loop over all ROIs:

```
Dim atROIResult(5) As AVTROIResult

For i = 0 To 4
  Set atROIResult(i) = atFeatureResult.ROIResults(i)
Next

For i = 0 To 4
  If atROIResult(i).Evaluation = False Then
    ' check cause of error
  End If
Next
```

The first possible cause of an error is that the ROI contains the wrong number of balls:

```
If atROIResult(i).FeatureEvaluation(handleObjectsInROI) = False Then
  sErrMsg = "Cycle " & iNumCycles & _
             ": wrong number of balls (" & _
             atROIResult(i).Value(handleObjectsInROI) & _
             ") in ROI " & sROINames(i)
  Call DisplayMessage(sErrMsg)
End If
```

Independently of this possible cause of error, features of the individual objects can have been evaluated as “not okay” (only one feature shown below). Note how you can access the indices of all objects evaluated as “not okay”:

```
Dim badObject As Variant

For Each badObject In atROIResult(i).BadObjectIndices
  ' check evaluation of features
  If atROIResult(i).ObjFeatureEvaluation(handleMinorRadius, _
                                          badObject) = False Then
    sErrMsg = "Cycle " & iNumCycles & _
               ": ball " & badObject & " on ROI " & sROINames(i) & _
               " has wrong minor radius (" & _
               atROIResult(i).ObjectValue(handleMinorRadius, _
               badObject) & ")"
    Call DisplayMessage(sErrMsg)
  End If
  ' check other features
Next
```

The error message also contains the number of the cycle in which the error occurred. The corresponding counter is incremented in the handler for `AVTView`’s event `CycleStart` which was introduced already in the previous section:

```
Private iNumCycles As Integer

Private Sub AVTView1_CycleStart()
  iNumCycles = iNumCycles + 1
End Sub
```

Appendix A

Mathematical Background of the Features

This chapter contains the equations for the more complex features.

A.1 Basic Moments

The (j,k)th moment of a blob B, denoted M_{jk} is defined as

$$M_{jk} = \sum_{(r,c)\in B} r^j c^k \tag{A.1}$$

with r and c being the row and column coordinates of the pixels. The moment $M_{00}(B)$ is identical with the *area* A of the blob B:

$$A = M_{00} = \sum_{(r,c)\in B} 1 \tag{A.2}$$

The *center of gravity* $(\overline{r}, \overline{c})$ is calculated from the zeroeth and first moments:

$$\overline{r} = \frac{M_{10}}{M_{00}} \qquad \overline{c} = \frac{M_{01}}{M_{00}} \tag{A.3}$$

Typically, higher moments are calculated relative to the center of gravity to make them translation invariant; these moments are then called *centralized moments*. The centralized (j,k)th moment of a blob B, denoted m_{jk} is defined as

$$m_{jk} = \sum_{(r,c)\in B} (r-\overline{r})^j \cdot (c-\overline{c})^k \tag{A.4}$$

To make moments scale invariant as well they can be divided by the blob area A and are then called *normalized moments*. The normalized (j,k)th moment of a blob B, denoted as μ_{jk} is defined as

$$\mu_{jk} = \frac{1}{A^{j+k}} \cdot m_{jk} = \frac{1}{A^{j+k}} \cdot \sum_{(r,c)\in B} (r-\overline{r})^j \cdot (c-\overline{c})^k \tag{A.5}$$

A.2 The Equivalent Ellipse

The parameters of the equivalent ellipse, i.e., the major radius R_{maj}, the minor radius R_{min}, and the orientation φ_E, are calculated from the normalized central moments as follows:

$$R_{maj} = \sqrt{2A \cdot (\mu_{20} + \mu_{02} + \sqrt{(\mu_{20} - \mu_{02})^2 + 4 \cdot \mu_{11}^2})} \tag{A.6}$$

$$R_{min} = \sqrt{2A \cdot (\mu_{20} + \mu_{02} - \sqrt{(\mu_{20} - \mu_{02})^2 + 4 \cdot \mu_{11}^2})} \tag{A.7}$$

$$\varphi_E = \arctan\left(\frac{-2\mu_{11}}{\mu_{20} - \mu_{02} + \sqrt{(\mu_{20} - \mu_{02})^2 + 4 \cdot \mu_{11}^2}}\right) \tag{A.8}$$

A.3 Complex Moments

Based on the basic moments, ActivFeatureCalc provides more complex moments which are invariant under other affine transformations, e.g., rotation or stretching.

$$
\begin{aligned}
\texttt{2nd Moments Phi 1} &= \mu_{20} + \mu_{02} && \text{(A.9)}\\
\texttt{2nd Moments Phi 2} &= (\mu_{20} - \mu_{02})^2 + \mu_{11} && \text{(A.10)}\\
\texttt{Central Moments Psi 1} &= \mu_{20} \cdot \mu_{02} - \mu_{11}^2 && \text{(A.11)}\\
\texttt{Central Moments Psi 2} &= A^2 \cdot ((\mu_{30}\mu_{03} - \mu_{21}\mu_{12})^2 - && \text{(A.12)}\\
&\quad 4 \cdot (\mu_{30}\mu_{12} - \mu_{21}^2)(\mu_{21}\mu_{03} - \mu_{12}^2))\\
\texttt{Central Moments Psi 3} &= A \cdot (\mu_{20} \cdot (\mu_{21}\mu_{03} - \mu_{12}^2) - \mu_{11} \cdot (\mu_{30}\mu_{03} - && \text{(A.13)}\\
&\quad \mu_{21}\mu_{12}) + \mu_{02} \cdot (\mu_{30}\mu_{12} - \mu_{21}^2))\\
\texttt{Central Moments Psi 4} &= A \cdot (\mu_{30}^2\mu_{02}^3 - 6\mu_{30}\mu_{21}\mu_{11}\mu_{02}^2 + && \text{(A.14)}\\
&\quad 6\mu_{30}\mu_{12}\mu_{02}(2\mu_{11}^2 - \mu_{20}\mu_{02}) + \mu_{30}\mu_{03}(6\mu_{20}\mu_{11}\mu_{02} -\\
&\quad 8\mu_{11}^3) + 9\mu_{21}^2\mu_{20}\mu_{02}^2 - 18\mu_{21}\mu_{12}\mu_{20}\mu_{11}\mu_{02} +\\
&\quad 6\mu_{21}\mu_{03}\mu_{20}(2\mu_{11}^2 - \mu_{20}\mu_{02}) + 9\mu_{12}^2\mu_{20}^2\mu_{02} -\\
&\quad 6\mu_{12}\mu_{03}\mu_{11}\mu_{20}^2 + \mu_{03}^2\mu_{20}^3)
\end{aligned}
$$

A.4 Gray Value Moments

The moments mixing spatial and gray value information, called *gray value moments* are defined in analogy to the basic moments in appendix A.1 on page 48, but now the gray value of a pixel, denoted as $g(r,c)$, is included in the calculation. To avoid a confusion with their "standard" counterparts, the gray value moments and the derived features are marked with a small 'g' in the upper left corner.

$$
{}^{g}M_{jk} = \sum_{(r,c)\in B} r^j c^k \cdot g(r,c) \qquad \text{(A.15)}
$$

Therefore, the *gray value area* ${}^{g}A$ of the blob B is calculated as:

$$
{}^{g}A = {}^{g}M_{00} = \sum_{(r,c)\in B} g(r,c) \qquad \text{(A.16)}
$$

and the *gray value center of gravity* $({}^{g}\overline{r}, {}^{g}\overline{c})$ as:

$$
{}^{g}\overline{r} = \frac{{}^{g}M_{10}}{{}^{g}M_{00}} \qquad {}^{g}\overline{c} = \frac{{}^{g}M_{01}}{{}^{g}M_{00}} \qquad \text{(A.17)}
$$

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The normalized (j,k)th gray value moment of a blob B, denoted as ${}^g\mu_{jk}$ is defined as

$$ {}^g\mu_{jk} = \frac{1}{{}^gA} \cdot \sum_{(r,c)\in B} (r - {}^g\overline{r})^j \cdot (c - {}^g\overline{c})^k \cdot g(r,c) \qquad \text{(A.18)} $$

From this, the parameters of the equivalent ellipse are calculated as follows:

$$ {}^gR_{maj} = \sqrt{2 \cdot ({}^g\mu_{20} + {}^g\mu_{02} + \sqrt{({}^g\mu_{20} - {}^g\mu_{02})^2 + 4 \cdot {}^g\mu_{11}^2})} \qquad \text{(A.19)} $$

$$ {}^gR_{min} = \sqrt{2 \cdot ({}^g\mu_{20} + {}^g\mu_{02} - \sqrt{({}^g\mu_{20} - {}^g\mu_{02})^2 + 4 \cdot {}^g\mu_{11}^2})} \qquad \text{(A.20)} $$

$$ {}^g\varphi_E = \arctan\left(\frac{-2\,{}^g\mu_{11}}{{}^g\mu_{20} - {}^g\mu_{02} + \sqrt{({}^g\mu_{20} - {}^g\mu_{02})^2 + 4 \cdot {}^g\mu_{11}{}^2}}\right) \qquad \text{(A.21)} $$

A.5 Gray Value Features

Gray value features evaluate the gray value of the pixels of a blob B, denoted as $g(r,c)$, with r and c being the row and column coordinates of the pixels. The *mean* gray value $\overline{g}$ and the *deviation* σ from it are calculated as follows:

$$ \overline{g} = \frac{1}{A} \cdot \sum_{(r,c)\in B} g(r,c) \qquad \text{(A.22)} $$

$$ \sigma = \sqrt{\frac{1}{A} \cdot \sum_{(r,c)\in B} (g(r,c) - \overline{g})^2} \qquad \text{(A.23)} $$

A.6 Texture Features

The texture features `Entropy` and `Anisotropy` are determined from the *histogram* of gray value frequencies $h(f(g))$ as follows:

$$ \texttt{Entropy} = -\sum_{g=0}^{255} h(f(g)) \cdot \log_2(h(f(g))) \qquad \text{(A.24)} $$

$$ \texttt{Anisotropy} = \frac{\sum_{g=0}^{k} h(f(g)) \cdot \log_2(h(f(g)))}{\texttt{Entropy}} \qquad \text{(A.25)} $$

with k being the smallest gray value for which $\sum_{g=0}^{k} h(f(g)) \geq 0.5$.

The texture features `Energy`, `Correlation`, `Homogenity`, and `Contrast` are determined from the *gray level co-occurrence matrix* $Cooc(g_1, g_2)$. This matrix stores the relative frequencies with which two gray values occur as neighbors in the blob B. The neighborhood is evaluated in the directions `0`°, `45`°, `90`°, and `135`°.

$$\texttt{Energy} = \sum_{(g_1,g_2) in Cooc} Cooc(g_1, g_2)^2 \tag{A.26}$$

$$\texttt{Correlation} = \frac{\sum_{(g_1,g_2) in Cooc} (g_1 - \overline{g}) \cdot (g_2 - \overline{g}) \cdot Cooc(g_1, g_2)}{\sigma^2} \tag{A.27}$$

$$\texttt{Homogenity} = \sum_{(g_1,g_2) in Cooc} \frac{Cooc(g_1, g_2)}{1 + (g_1 - g_2)^2} \tag{A.28}$$

$$\texttt{Contrast} = \sum_{(g_1,g_2) in Cooc} (g_1 - g_2)^2 \cdot Cooc(g_1, g_2) \tag{A.29}$$

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