LA-UR-14-23625
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Title: MAMA Software Features: Quantification Verification Documentation-1

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Intended for: Web

Issued: 2014-05-21

MAMA Software Features:

Quantification Verification Documentation-1

3/31/2014

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Abstract:

This document reviews the verification of the basic shape quantification attributes in the MAMA software against hand calculations in order to show that the calculations are implemented mathematically correctly and give the expected quantification results.

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MAMA Quantification Verification and Validation Documentation-1

Contents

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1: Basic Attribute Calculation Verification

1.0 Overview:

The Following mama calculation algorithms for the following attributes have been verified to be implemented correctly to give accurate calculations as defined:

> **☑Area, ☑Pixel count, ☑Convex hull, ☑perimeter, ☑convex hull perimeter, ☑ ECD, ☑perimeter convexity, are within 2 % of the directly measured attribute for a variety of shapes.**
>
> **☑Convexity, ☑Circularity, ☑Roundness, are within 3% of the directly measured attribute for a variety of shapes.**
>
> **☑ Ellipse major and minor axes and ☑Ellipse Aspect ratio are within 2% for aspect ratio < 2 objects, and then get larger (3.6% for an aspect ratio 3 object), but have not been tested on a larger range of ellipse eccentricities yet. They cannot be verified similar to these calculations with non-elliptical shapes (direct measurement), so further verification, as required, will be reported separately.**

***These differences include the differences that result from the software segmentation of the object. Even with that added source of variance, the calculated attribute values are within the accuracy with which objects can be robustly represented in pixel space.**

The calculation verification is limited to objects without a self-intersection points, and the calculations should be used with careful understanding of how the calculation is performed in objects with holes and highly convoluted objects in order to understand what is being measured.

> **☐ Aspect ratio Chordal is within 3% of the directly measured attribute for most shapes, but a calculation 'bug' leads to a large difference in some symmetrical convex shapes due to multiple near-equivalent options for the chordal diameters that can be used in the calculation. This calculation functions mathematically correctly, but the software does not always select the same chordal diameters that users would, leading to a difference. There is no one right calculation in these cases—the preferred chordal set must be defined. This 'definition' has not been set with enough 'tolerance' in the software so that even given minor variations in the representation of the shape in pixel space, the same chordal set is always used.**

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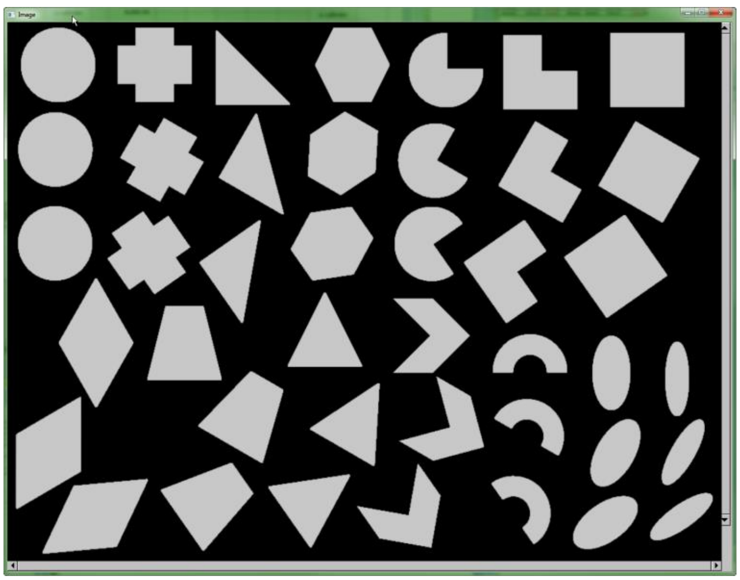
1.2 The Verification Test Set

14 shapes for which attributes could be mathematically calculated were plotted in a TIFF figure, with each shape represented 3 times covering different pixel positioning and orientation. Each shape had a side or diameter approximately 100 pixels (ECD range from 65-114). The attributes were calculated using mathematical formulas for what the values would be in a real shape, and were then directly measured in the image by direct pixel counts on each representation of each shape. For perimeter calculations, the measurements were based on the perimeter pixel count and method the software uses to calculate the shape—perimeter pixels are either counted as 1 if in line, or sqrt(2) if on diagonal. Convex hull perimeter is similar calculated, but the only the pixel that form the convex hull are used, and the length of the vector between convex hull pixels is directly counted or measured on the image using commercial image analysis software tools that return pixel counts.



Ellipse diameters, Ellipse aspect ratio and Hu moments were not fully verified in this test since the calculations could not be done by hand but require a software implementation of the fitting and attribute equations, which could only give us a comparison to another code based at best. However, ellipse calculations can be verified against ellipse shapes where the final fit ellipse can be assumed to be identical to the mathematical ellipse that was used to draw the shape.

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1.2 Results

1.2.1 Results for Attributes 1) Area, 2) Convex hull area, 3) pixel count, 4) Perimeter, 5) Convex hull perimeter, 6) ECD, and 10) Perimeter convexity:

The MAMA calculated attribute is less than 2% difference in all cases than the hand-measured attribute with ideal segmentation. In almost all cases, the differences are less than 1%. The tables below, the average % difference calculated between measured average for each shape and the MAMA calculated average for each shape, for each attribute. The max and min observed differences –the largest (not averaged) differences between MAMA and directly measured--attribute for all shapes are at the bottom of each % difference column. These differences are largest in cases where an object is aligned with straight sides on pixel axis, and the segmentation appears to cut off some pixels. Although not shown below, the calculations are accurately quantifying the object as segmented, but the segmentation needs to improve in these cases. (This is a high priority improvement, but will not ultimately have much effect on the uncertainty in these calculations, which will be reported in a secondary document.)

The variation in the attributes measurements of these shapes as they are rotated and represented at different orientation in an image are a similar magnitude or LARGER than the differences between the MAMA software calculation and the measured value for each attribute. In other words, <u>the variance in representing the shape in pixels at different rotations/positions in an image is larger than the difference between the measured attribute and the MAMA software calculated attribute, even including segmentation variation.</u> For example, the **measured** pixel count for a 100 pixel side right angle triangle plotted in the image a 3 orientations ranged from 5247 to 5333 pixels (86 pixel difference, 1.6% variance). MAMA software calculated 5248 to 5331 pixels, with each calculated value within 0.04% of measured (max difference of 2 pixels from measured). For perimeter the variance is far larger: The perimeter as measured for a 100 pixel side square plotted in 3 orientation range from 400 to 428 pixels (28 pixel difference, 6.7% variance). MAMA calculated 401-427 pixels; the worst calculation was 3 pixels smaller (0.8% difference) than the same object's directly measured perimeter).

Importantly, for users understanding of image analysis calculation, ALL measured attributes differ from the same attribute calculated from mathematical formulas. This is, of course, expected when a continuous object is represented with a finite number of square pixels. These differences can be seen in the tables below as well (Math column compared to measured column). We cannot expect to have equivalent calculations to a smooth curved surface when the object is represented in very small (<10000) number of pixels.

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1.2.2 Results for Attributes 8) Roundness, 9) Circularity, 11) Area Convexity:

The MAMA calculated attribute is less than 3% difference in all cases from the hand measured attribute. In fact, all calculations are less than 2% difference except an on-axis square which is affected by the segmentation issue noted above. As above, the variation from representing the shape in different orientations is larger (For example, the measured Circularity ranged from 0.60 to 0.65 (8.3% difference) for an diamond shape depending on orientation, while the difference between calculated and measured ranged from -1.5 to 1.4%. The representational variation of Area convexity and Perimeter convexity are much lower than Circularity/roundness, and this will be shown in an accompanying (pending) uncertainty document. This makes the convexity attributes much more robust.

1.2.3 Results for Attribute 7) Aspect Ratio Chordal:

Verification testing on the Aspect Ratio chordal shows similar results to Roundness and circularity. The MAMA calculated attribute is less than 3% difference in **almost all** cases than the hand measured attribute, with two exceptions that demonstrate an issue in the calculation for some objects, which is described at the end of this document. As above, the variation from representing the shape in different orientations is much larger than the difference between the hand measured and MAMA calculated values. This bug will be fixed and this attribute will be verified again with the same test set so it can be compared to all other attributes.

1.2.4 Results for Aspect Ratio Ellipse:

The ellipse calculations can be tested against a reduced set of shapes for which the fit ellipse should match the actual object shape that would be derived—circles and ellipse. With the three elliptical objects in the test set, the MAMA software determined Ellipse Major and Minor axes and the Ellipse aspect ratio are within 3.6% of the measured value for these attributes.

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1.3 A Tricky Issues in Calculating Aspect Ratios:

In High symmetry objects, there is an insufficient catch to force the software to check which of multiple near-equivalent chordal distances should be used. A minor 1 pixel in 100 (1%) difference in chordal length will change what chord is designated the maximum, although this difference is well within the representational uncertainty of the object in pixel space, and well within the segmentation and instrument uncertainties we expect. The max chordal diameter needs to be defined with an uncertainty tolerance to avoid minor variations in the object causing a change in which of near equivalent chordal diameters are used, and a prioritization of equivalent chord sets need to be defined.. (This is needed on any method to do a measured, rather than a fitted, aspect ratio.) The orthogonal chord to the maximum chord is set to a tolerance of 5 degrees from orthogonal, and uses the absolute maximum that it can find within this tolerance, so the aspect ratio returned is typically the lowest possible given the initial maximal chord. However, there is not an equivalent initial tolerance to the maximal chordal—a 101 pixel chord will always be chosen over a 100 pixel chord, even when this difference is within the segmentation/perimeter uncertainty. In the case of shapes such as “pacman” (a ¾ circle in our case) with multiple near equivalent maximum chords, if the initial maximum chord aligns so that the orthogonal can span the diameter of the circle, the aspect ratio returned is close to 1.0. However, is the initial maximal chord happens to be (by 1 pixel) oriented orthogonal to the missing ‘wedge’, the maximum orthogonal cord is limited to a length far shorter than the diameter, so the aspect ratio returned is greater than 1. (in our case, 1.2) A ~2-5% tolerance on what is truly “maximum” chordal diameter, with perhaps a tighter tolerance on the orthogonal chord, with the prioritization to give the minimum aspect ratio within that set should both tighten uncertainty and limit variation in this calculation.

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1.4 Summary Result tables:

Selected verification numbers from the full data set are shown in the tables below. All are based in pixels.

Calculation Verification Mathematical formula, Directly Measured value, MAMA calculated value, and % difference between MAMA and Measured. In all cases, the values represent the average of 3 representation of each shape.												
	1. AREA				2. Convex Hull Area				3. Pixel Count			
Shape	Math	Measured	MA MA	% Diff	Math	Measured	MAMA	% Diff	Math	Measured	MAMA	% Diff
ARC	3134	3295	3304	-0.06	4127	4231	4230	0.56	3134	3295	3303	-0.07
Chevron	5200	5401	5399	-0.07	7600	7849	7840	-0.26	5200	5401	5399	-0.07
CIRCLE	7854	7946	7962	0.01	7854	8025	8034	-0.14	7854	7946	7962	0.01
Diamond	8874	9050	8977	-0.11	8874	9106	9115	0.39	8874	9050	8977	-0.11
Ellipse 1	4084	4116	4121	0.00	4084	4175	4176	-0.10	4084	4116	4121	0.00
Ellipse 2	2538	2617	2615	-0.06	2538	2680	2669	-0.34	2538	2617	2615	-0.06
Hexagon	7500	7740	7717	0.00	7500	7827	7827	0.15	7500	7740	7717	0.00
Iso-Triangle	5151	5283	5321	0.64	5151	5415	5421	0.14	5151	5283	5321	0.64
L	7500	7790	7730	-0.42	8750	8996	8965	0.12	7500	7790	7729	-0.42
PacMan	5890	6135	6155	-0.01	7140	7343	7309	-0.33	5890	6135	6155	-0.02
Plus	7500	7796	7730	-0.46	8750	8970	8913	-0.20	7500	7796	7729	-0.46
Right Triangle	5196	5330	5303	-0.01	5196	5434	5425	0.78	5196	5330	5303	-0.01
Square	10000	10143	10034	-0.63	10000	10219	10225	0.50	10000	10097	10034	-0.63
Trap-azoid	7600	7687	7712	0.38	7600	7785	7833	0.12	7600	7687	7712	0.38
Max				1.77				1.14				1.77
Min				-1.89				-0.84				-1.89

Calculation Verification Mathematical formula, Directly Measured value, MAMA calculated value, and % difference between MAMA and Measured. In all cases, the values represent the average of 3 representation of each shape .												
	4. Perimeter				5. Convex Hull Perimeter				6. ECD			
Shape	Math	Measured	MA MA	% Diff	Math	Measured	MAMA	% Diff	Math	Measured	MAMA	% Diff
ARC	292	303	303	0.18	261	263	262	-0.54	63	65	65	-0.05
Chevron	387	411	401	-0.07	345	342	346	-0.26	81	83	83	-0.05
CIRCLE	314	332	334	0.64	314	317	318	-0.16	100	101	101	0.00
Diamond	400	435	424	0.05	400	407	402	-0.64	106	107	107	-0.06
Ellipse 11	246	261	260	0.36	246	249	248	-0.30	72	72	72	-0.01
Ellipse 2	223	236	236	0.59	223	226	226	-0.46	57	58	58	-0.05
Hexagon	324	344	344	0.17	324	328	327	-0.14	98	99	99	0.00
Iso-Triangle	322	342	342	-0.01	322	326	325	-0.10	81	82	82	0.31
L	400	427	415	-0.25	371	371	370	-0.32	98	100	99	-0.22
PacMan	336	353	353	0.42	306	312	310	-0.50	87	88	89	-0.01
Plus	400	425	413	-0.47	341	346	344	-0.43	98	100	99	-0.24
Right Triangle	341	364	357	0.10	341	343	342	0.10	81	82	82	-0.02
Square	400	428	417	-0.21	400	401	399	-0.41	113	114	113	-0.32
Trap-azoid	360	376	374	0.24	360	358	357	-0.26	98	99	99	0.18
Max				0.98				0.45				1.77
Min				-1.22				-0.87				-1.89

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Calculation Verification: Mathematical formula, Directly Measured value, MAMA calculated value, and % difference between MAMA and Measred. In all cases, the values represent the average of 3 representation of each shape ,									
	7. Aspect Ratio, Chordal				Aspect Ratio, Ellipse	8. Roundness			
Shape	Math	Meas'	MA MA	% Diff	MAMA	Math	Meas'	MAMA	% Diff
ARC	2.16	2.04	2.03	-0.28	1.72	2.17	2.22	2.22	0.53
Chevron	1.00	1.02	1.01	0.01	1.04	2.29	2.49	2.38	-0.01
CIRCLE	1.00	1.00	1.00	0.01	1.00	1.00	1.11	1.12	1.29
Diamond	1.72	1.72	1.71	-0.55	1.72	1.43	1.66	1.60	0.24
Ellipse 11	1.98	1.89	1.91	0.29	1.94	1.17	1.32	1.31	0.75
Ellipse 2	3.13	2.96	2.99	-0.53	3.09	1.56	1.69	1.70	1.33
Hexagon	1.22	1.22	1.22	0.07	1.14	1.11	1.22	1.22	0.36
Iso-Triangle	1.22	1.23	1.23	-0.19	1.17	1.60	1.77	1.75	-0.61
L	1.84	1.76	1.71	-2.52	1.31	1.70	1.86	1.77	-0.05
PacMan	1.00	1.04	1.09	6.43	1.21	1.52	1.62	1.61	0.88
Plus	1.00	1.00	1.00	0.49	1.01	1.70	1.85	1.75	-0.46
Right Triangle	1.94	1.93	1.92	-0.76	1.76	1.78	1.98	1.91	0.26
Square	1.00	1.00	1.00	0.11	1.01	1.27	1.44	1.38	0.25
Trap-azoid	1.20	1.15	1.15	-0.74	1.20	1.36	1.46	1.44	0.12
Max				14.93					2.44
Min				-4.70					-1.74

CalculationVerification: Mathematical formula, Directly Measured value, MAMA calculated value, and % difference between MAMA and Measured. In all cases, the values represent the average of 3 representation of each shape ,												
	9. Circularity				10. Perimeter Convexity				11. Area Convexity			
Shape	Math	Measured	MA MA	% Diff	Math	Measured	MAMA	% Diff	Math	Measured	MAMA	% Diff
ARC	0.46	0.45	0.45	-0.45	0.89	0.87	0.86	-0.72	0.76	0.78	0.78	-0.64
Chevron	0.44	0.40	0.42	0.06	0.89	0.83	0.86	-0.19	0.68	0.69	0.69	0.17
CIRCLE	1.00	0.90	0.90	-1.27	1.00	0.96	0.95	-0.80	1.00	0.99	0.99	0.15
Diamond	0.70	0.60	0.63	-0.22	1.00	0.94	0.95	-0.70	1.00	0.99	0.98	-0.49
Ellipse 11	0.86	0.76	0.76	-0.74	1.00	0.95	0.95	-0.66	1.00	0.99	0.99	0.10
Ellipse 2	0.64	0.59	0.59	-1.28	1.00	0.96	0.95	-1.05	1.00	0.98	0.98	0.28
Hexagon	0.90	0.82	0.82	-0.35	1.00	0.95	0.95	-0.32	1.00	0.99	0.99	-0.15
Iso-Triangle	0.62	0.57	0.57	0.63	1.00	0.95	0.95	-0.09	1.00	0.98	0.98	0.50
L	0.59	0.54	0.57	0.07	0.93	0.87	0.89	-0.07	0.86	0.87	0.86	-0.55
PacMan	0.66	0.62	0.62	-0.86	0.91	0.88	0.88	-0.92	0.82	0.84	0.84	0.31
Plus	0.59	0.54	0.57	0.48	0.85	0.81	0.83	0.04	0.86	0.87	0.87	-0.26
Right Triangle	0.56	0.51	0.53	-0.24	1.00	0.94	0.96	0.00	1.00	0.98	0.98	-0.78
Square	0.79	0.70	0.73	-0.22	1.00	0.94	0.96	-0.21	1.00	0.99	0.98	-1.12
Trap-azoid	0.74	0.68	0.69	-0.11	1.00	0.95	0.95	-0.50	1.00	0.99	0.98	0.26
Max				1.83				1.00				1.43
Min				-2.38				-1.45				-2.81

Calculation Verification: Mathematical formula, Directly Measured value, MAMA calculated value, and % difference between MAMA and Measured. and % difference between Mama and Math. In all cases, the values represent the average of 3 representation of each shape ,															
	12. EllipseMajor					13. Ellipse Minor					14. Ellipse-aspect Ratio				
Shape	Math	Measured	MA MA	% Diff Mama-Meas'rd	% Diff Mama -Math	Math	Measured	MAMA	% Diff Mama-Meas'd	% Diff Mama Math	Math	Measured	MAMA	% Diff Mama - Meas'rd	% Diff Mama Math
CIRCLE	100	101.7	100.8	-0.88	0.80	100	101.6	100.	-0.9	0.57	1.00	1.00	1.00	0.07	0.23
Ellipse 11	100	101.0	100.8	-0.208	0.823	52	52.9	52.1	-1.7	0.11	1.92	1.91	1.94	1.46	0.71
Ellipse 2	101	100.6	101.4	0.797	0.431	32	33.5	32.9	-1.8	2.73	3.16	3.01	3.09	2.57	-2.2
Max				1.89	1.44				0.99	0.80				3.58	0.99
Min				-1.10	0.06				-3.16	-0.84				-0.04	-3.16

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