The Power of Machine Learning

Image analysis for particle size and shape

Innopharma

- Innopharma Labs founded 2009
- Expanded into:
  - *Innopharma Education*
  - *Innopharma Technology*
  - *Innopharma Technical Services*

- HQ: Dublin, Ireland
- ~120 employees experienced in STEM, pharma, manufacturing, IT, Software Development

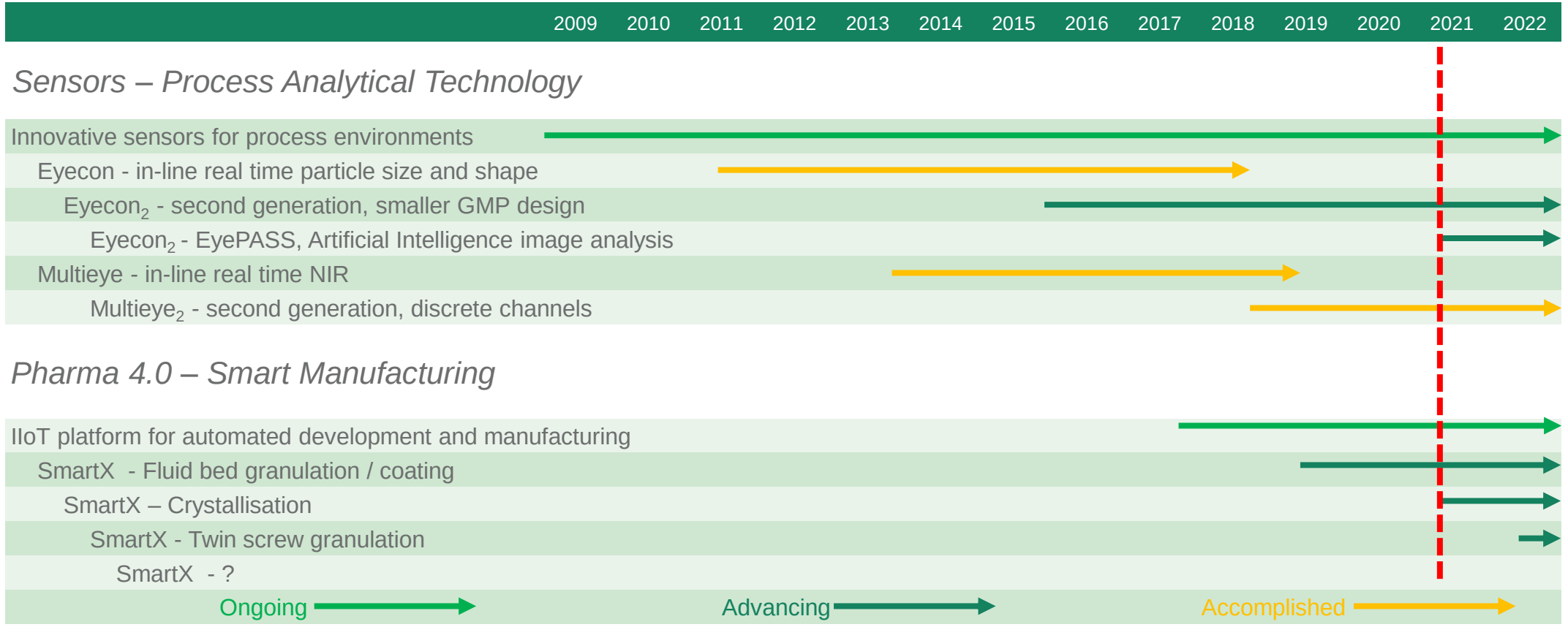
Innopharma technology

The Journey

Innopharma technology

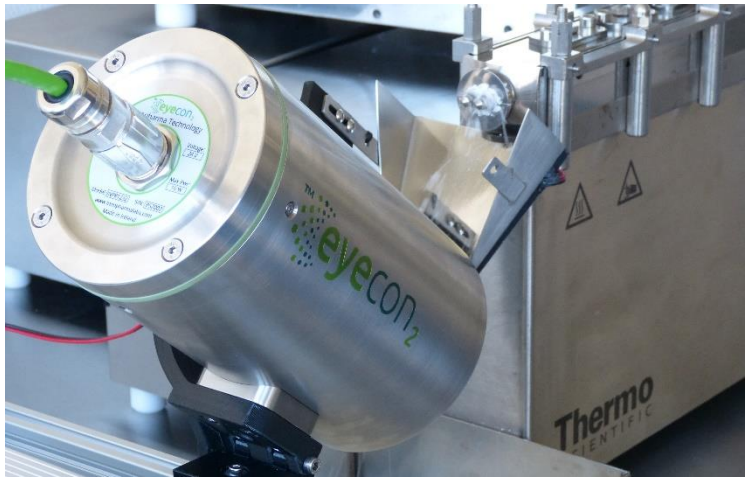
eyecon$_2$ multieye$_2$ SmartX

Solutions for Advanced Manufacturing



Eyecon$_2$ Technical Specifications

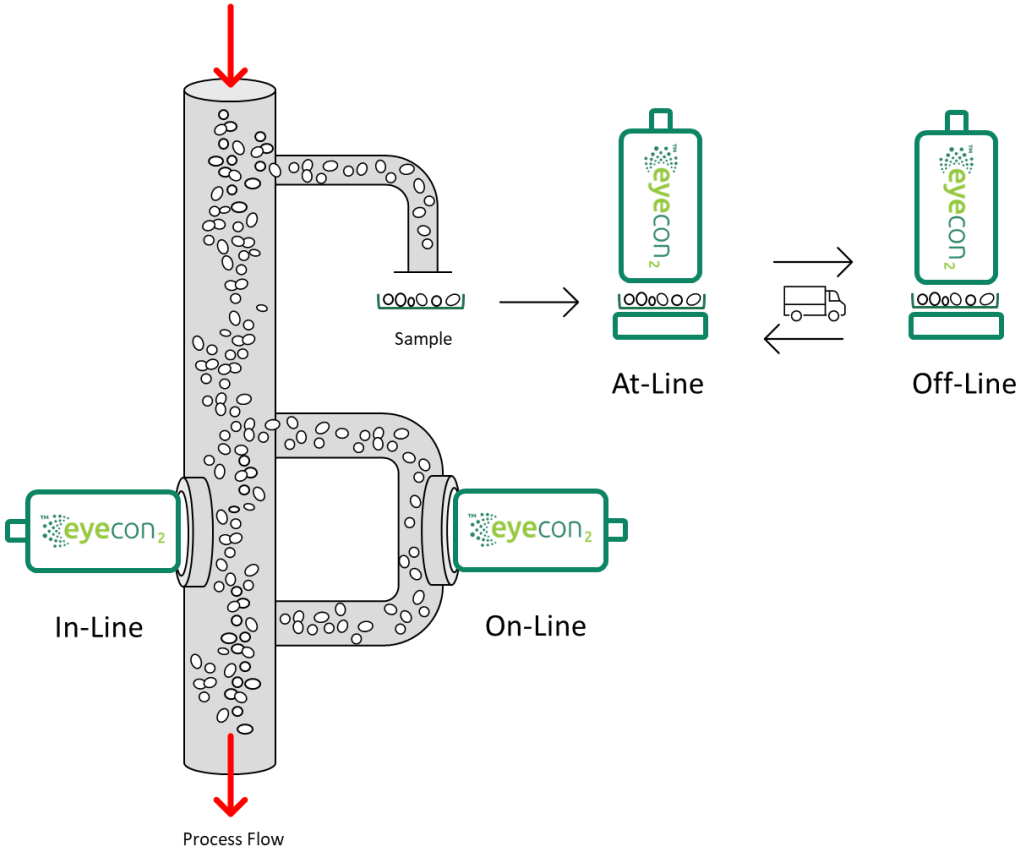
Size Range	50 to 5500 µm
Casing materials	304 Stainless Steel, Glass, Silicon (gaskets)
Imaging Area	11.25 x 11.25 mm
Output	PDF. CSV, JPEG full PSD D5-D95.
Instrument Ratings	GMP compliant design EyePASS is both 21 CFR part 11 & GAMP5 Compliant CE Marking ATEX zones 2/22, IP65.
Configurations	In-line and at/offline
Communication	Ethernet and USB OPC UA, OPC DA 3.0



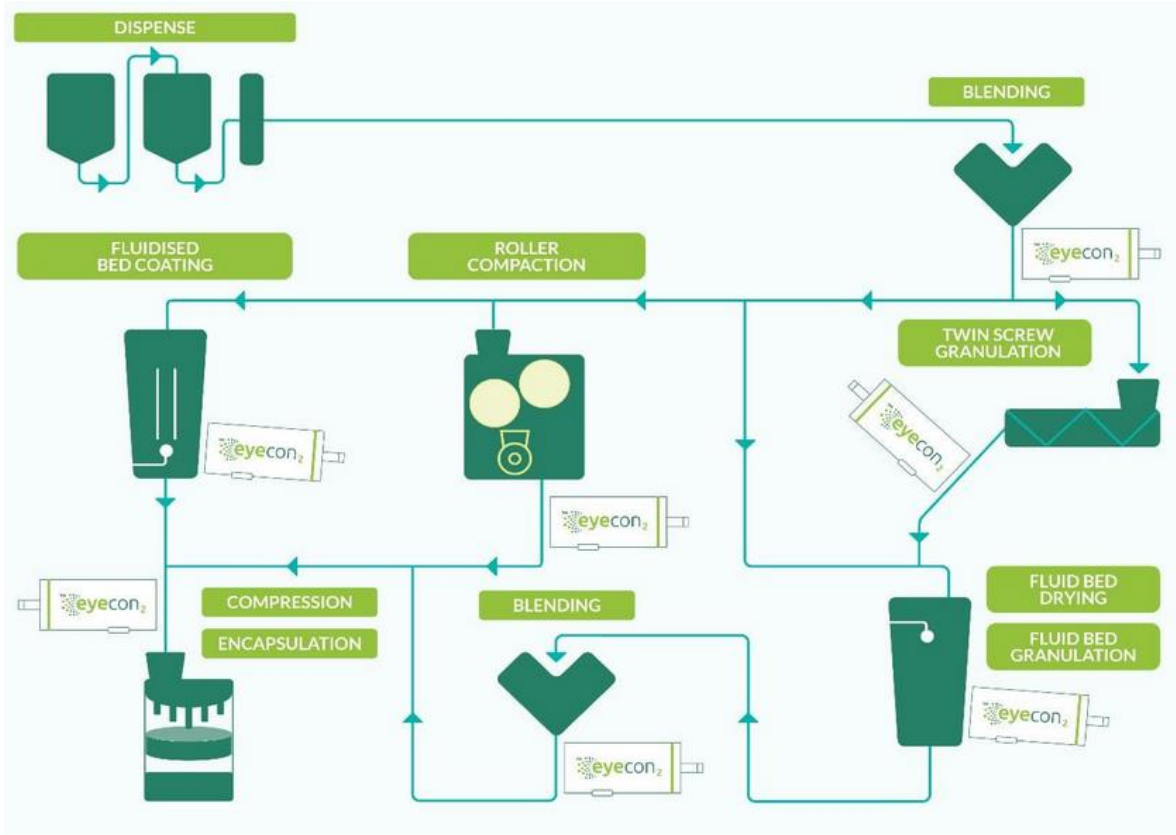
- ✓ *In-line*
- ✓ *At-line*
- ✓ *Non product contact*
- ✓ *Real time*

Small particles are Big deal

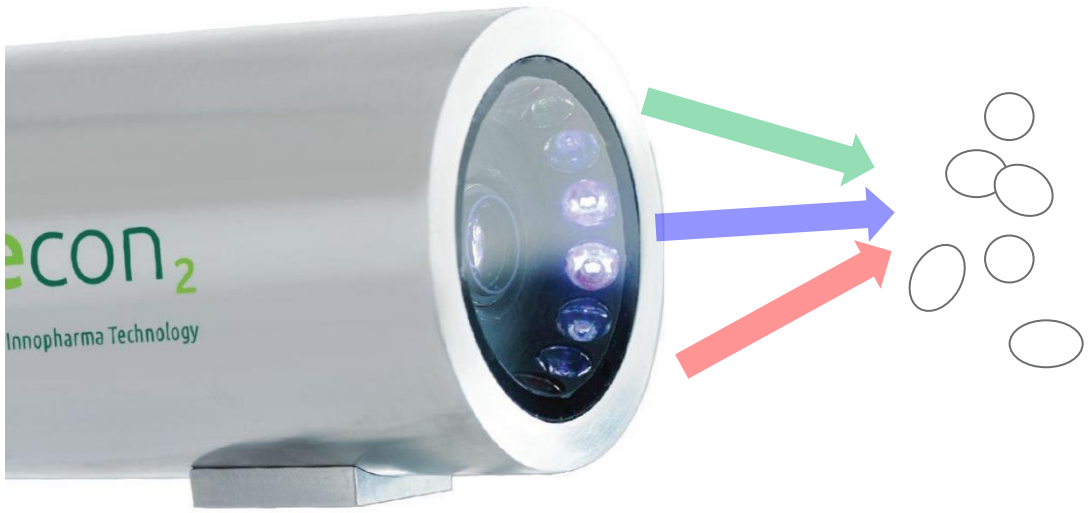
Configurations



Processes



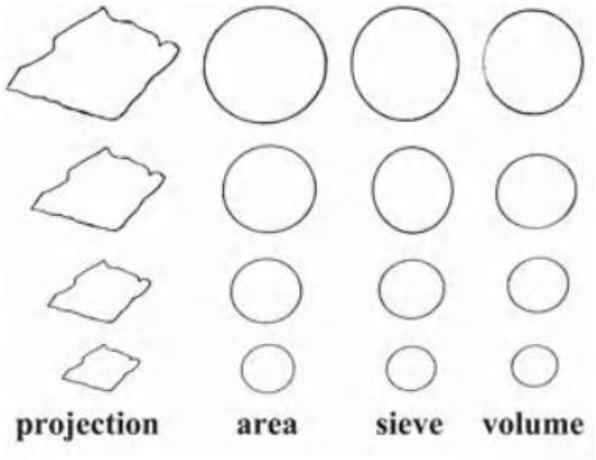
Method of Operation: Image Capture



- A flash-imaging technique is used with an extremely short light-pulse to illuminate moving particles for image capture
- Red, Green and Blue LEDs illuminating the sample from different angles for detection of particle boundaries

Particle size methods

Particle size methods are not created equally, they all have their advantages and disadvantages



2.1 Particle Size

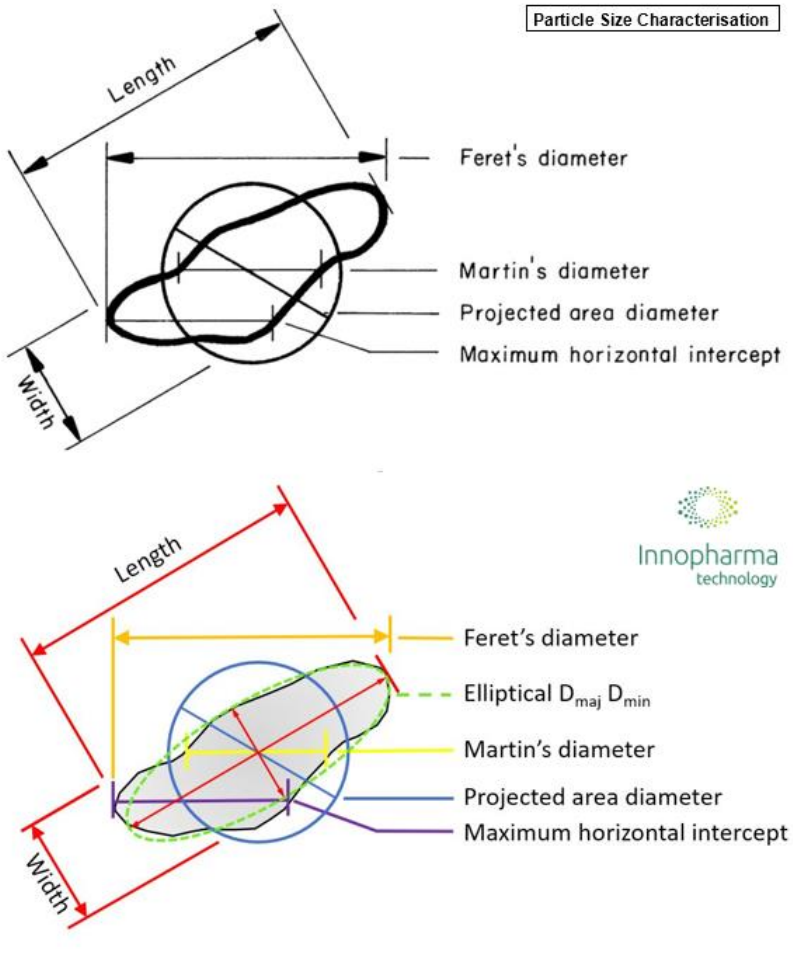
Fig. 2.2 Equivalent sphere concept for arbitrary particles

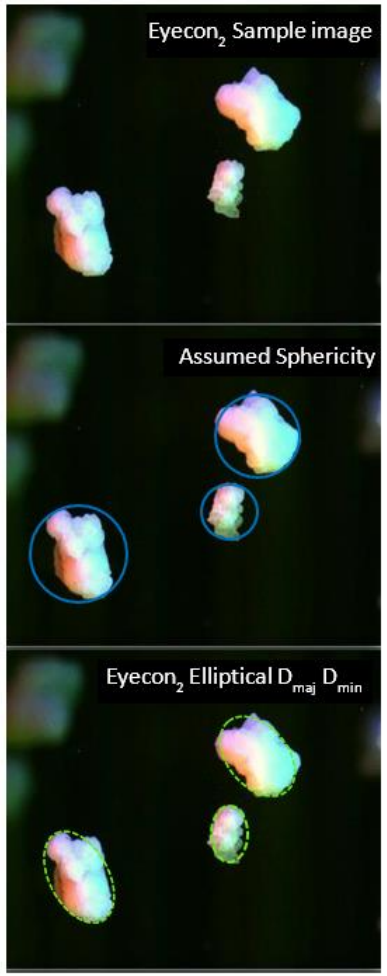
From: Particle Size Measurements, Fundamentals, Practice, Quality,Henk G. Merkus

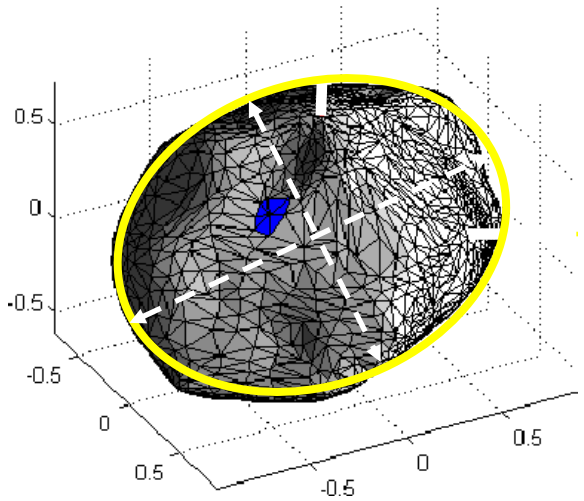
Horiba Particle Guidebook 2022

From: https://static.horiba.com/fileadmin/Horiba/Products/Scientific/Particle_Characterization/Particle_Guidebook_2022.pdf

Method of Operation: Image Capture







- Each particle initially identified
- Best-fit ellipse calculated
- Major & minor diameters computed
- PSD/D-values determined

Eyecon$_2$ Data Output

Eyecon$_2$ Data Output

Particle Size Report

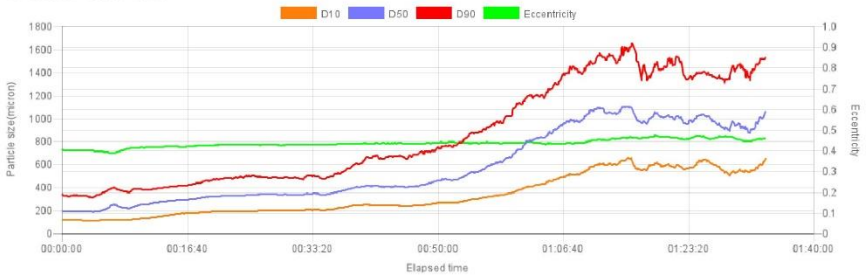
Batch Details

Material	Gran_171004_R2	**Configuration**	Config_170922_Gran	**Start time**	2017-10-04 14:55:13
Batch Number	attempt2	**Started by**	admin	**End time**	2017-10-04 16:28:59
Sublot		**Number of particles**	543602	**Duration**	1:33:47
Instrument details	EYECON2	**Eyecon serial number**	PS2003	**Eyepass version**	1.1.4

Alarms & notifications

System events	No

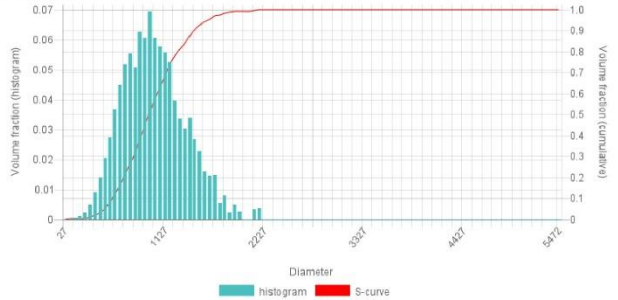
Results: Process Profile



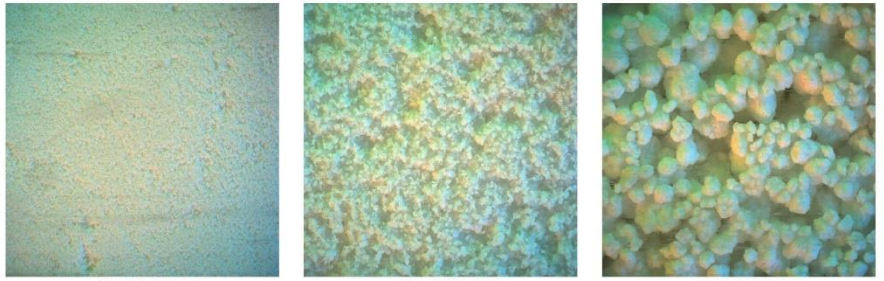
Results: End Point

Data based on final 300 seconds of measurement

Dv10	582.64
Dv25	752.50
Dv50	981.33
Dv75	1224.60
Dv90	1480.19
Dn10	109.05
Dn25	254.69
Dn50	483.43
Dn75	714.25
Dn90	964.79
Mean	515.82
Median	483.43
Std deviation	326.08
Eccentricity mean	0.4511
Eccentricity RSD	0.4326



Sample Images



2017-10-04 14:55:14 | 2017-10-04 15:42:06 | 2017-10-04 16:28:54

Signature: _____ Date: _____

Eyecon$_2$ Data Output

Eyecon Particle Size Report - Innopharma Technology

Batch Details

Material	Batch Nu	n/a	Configur	Started I	Start dat	Start tim	End date	End time	Duration (seconds)
Gran_171004	attempt:	n/a	Config_1	admin	2017-10-	14:55:13	2017-10-	16:28:59	5626.06

Instrument Details

Model	Serial nc	EyePASS ver
EYECON2	PS2003	1.1.4

Configuration Details

Name	Mode	Image st	Short du	Integrati	Min. Rep	Max. Rep	Max. det	False ag	Edge cor	Analysis	Material	Alarms a	Report t	Product	All came	R camera	G camer	B camera	R LED ga	G LED ga	B LED ga	Focus position (Eyecon 2 only)
Config_17092	In Line	12	0	120	25	5000	1400	0.25	60	301	0	false	Default	300	53	100	40	75	60	50	251	

End Point Results - calculated from final 300 seconds of process

			D_v10	D_v50	D_v90	D_n10	D_n50	D_n90	Mean di	Median	Std devi	d1 avera	d2 avera	Shape m	Shape R	5% vol	10% vol	15% vol	20% vol	25% vol	30% vol	35% vol	40% vol	45% vol	50% vol	55% vol	60% vol	65% vol	70% vol	75% vol	80% vol	85% vol	90% vol	95% vol	100% vol
			582.64	981.33	1480.19	109.05	483.43	964.79	515.82	483.43	326.08	553.18	478.46	0.4511	0.4326	491.25	582.64	649.26	700.41	752.5	802.81	854.17	896.13	938.96	981.33	1022.46	1069.56	1121.73	1169.32	1224.6	1303.89	1400.34	1480.19	1616.77	2183.39

Process Profile - all results based on integration period of 120 seconds

Date	Time	Elapsed	D_v10	D_v50	D_v90	D_n10	D_n50	D_n90	Mean di	Median	Std devi	d1 avera	d2 avera	Shape m	Shape R	5% vol	10% vol	15% vol	20% vol	25% vol	30% vol	35% vol	40% vol	45% vol	50% vol	55% vol	60% vol	65% vol	70% vol	75% vol	80% vol	85% vol	90% vol	95% vol	100% vol
04/10/2017	14:55:14	0.63	115.43	197.14	340.44	107.46	124.48	203.48	141.31	124.48	46.69	149.11	133.51	0.4027	0.3867	110.98	115.43	120.62	126.04	132.02	139.79	150.15	178.79	189.88	197.14	204.67	216.19	227.27	246.14	269.78	290.04	314.68	340.44	366.5	469.02
04/10/2017	14:55:22	8.45	115.45	195.99	331.33	107.62	124.53	203.29	141.15	124.53	45.74	148.98	133.31	0.4039	0.3853	111	115.45	120.55	125.89	131.59	138.04	147.85	175.21	188.15	195.99	203.27	212.92	225.5	238.21	261.21	283.12	303.03	331.33	361.31	469.02
04/10/2017	14:55:29	16.23	115.44	195.96	323.75	107.72	124.37	203.84	140.96	124.37	45.34	148.65	133.27	0.4013	0.3828	110.83	115.44	120.37	125.51	130.96	137.76	147.27	169.1	187.45	195.96	203.6	212.2	222.89	236.55	260.29	280.66	297.85	323.75	358.87	469.02
04/10/2017	14:55:37	24.02	115.75	196.7	325.89	107.93	124.55	204.71	141.3	124.55	45.54	149.01	133.58	0.4008	0.384	111.04	115.75	120.61	125.82	131.45	138.13	147.83	171.39	188.45	196.7	203.98	213.01	223.14	237.7	261.2	279.73	298.36	325.89	361.73	469.02
04/10/2017	14:55:45	31.83	115.67	196.65	324.43	107.99	124.46	204.75	141.25	124.46	45.5	148.97	133.54	0.4011	0.384	111.08	115.67	120.44	125.69	131.32	138.04	147.87	171.4	188.38	196.65	203.98	212.69	223.28	236.88	260.85	279.22	297.57	324.43	364.11	469.02
04/10/2017	14:55:53	39.64	115.69	196.38	326.19	108.1	124.43	204.67	141.17	124.43	45.43	148.88	133.45	0.4011	0.3842	111.11	115.69	120.45	125.59	131.04	137.84	147.56	170.07	187.77	196.38	203.94	212.55	223.11	236.73	260.98	279.94	298.61	326.19	365.81	469.02
04/10/2017	14:56:01	47.44	115.57	195.5	323.55	108.08	124.54	204.29	140.99	124.54	45.07	148.7	133.28	0.4012	0.3847	111.01	115.57	120.4	125.51	130.87	137.55	146.64	166.85	187.09	195.5	203.37	211.46	221.64	234.66	258.38	278.44	296.3	323.55	364	469.02
04/10/2017	14:56:08	55.24	115.57	195.35	323.5	108.05	124.54	204.13	140.97	124.54	45.06	148.67	133.27	0.4011	0.3846	110.99	115.57	120.38	125.5	130.86	137.49	146.49	166.73	186.86	195.35	203.19	211.33	221.6	235.24	258.91	278.82	296.22	323.5	364.66	469.02
04/10/2017	14:56:16	63.04	115.6	195.18	322.5	108.01	124.57	203.94	140.94	124.57	45.01	148.67	133.22	0.4018	0.3842	110.98	115.6	120.41	125.47	130.85	137.35	146.33	166.17	186.77	195.18	203.08	211.16	221.43	234.71	259.11	278.97	296.33	322.5	365.17	469.02
04/10/2017	14:56:24	70.85	115.64	195.12	324.22	107.99	124.58	203.75	140.88	124.58	45.03	148.59	133.17	0.4016	0.3845	110.98	115.64	120.42	125.51	130.83	137.27	146.35	166.22	186.7	195.12	203.05	211.23	221.46	234.53	259.46	279.02	296.91	324.22	367.26	541.35
04/10/2017	14:56:32	78.66	115.63	195.34	326.43	107.92	124.53	203.75	140.85	124.53	45.1	148.56	133.13	0.4015	0.3853	110.95	115.63	120.42	125.46	130.84	137.27	146.49	166.38	186.72	195.34	203.15	211.39	221.56	234.69	260.13	279.69	298.13	326.43	370.49	541.35
04/10/2017	14:56:40	86.47	115.61	195.35	329.01	107.93	124.5	203.62	140.8	124.5	45.1	148.52	133.09	0.4017	0.3856	110.98	115.61	120.41	125.43	130.8	137.25	146.4	166	186.65	195.35	203.03	211.29	221.51	234.87	260.29	280.4	298.86	329.01	371.2	541.35
04/10/2017	14:56:47	94.25	115.56	195.32	331.33	107.91	124.45	203.48	140.72	124.45	45.07	148.43	133.01	0.4015	0.3859	110.94	115.56	120.36	125.35	130.74	137.15	146.31	165.46	186.48	195.32	203.02	211.26	221.52	235	260.29	280.58	298.86	331.33	371.98	541.35
04/10/2017	14:56:55	102.06	115.52	194.99	329.47	107.88	124.42	203.41	140.65	124.42	44.95	148.37	132.94	0.4017	0.3864	110.93	115.52	120.28	125.26	130.67	137	146.06	164.55	186.33	194.99	202.79	210.8	220.99	234.32	259.63	279.82	297.5	329.47	370.68	541.35
04/10/2017	14:57:03	109.88	115.55	195.2	330.58	107.89	124.43	203.59	140.7	124.43	45.02	148.42	132.99	0.4017	0.3864	110.97	115.55	120.31	125.31	130.74	137.15	146.24	164.73	186.42	195.2	203.01	211.02	221.3	234.58	259.84	280.28	298.76	330.58	371.7	541.35
04/10/2017	14:57:11	117.68	115.54	195.11	331.45	107.88	124.41	203.67	140.66	124.41	44.95	148.36	132.95	0.4016	0.3865	110.97	115.54	120.28	125.27	130.7	137.08	146.03	164.28	186.33	195.11	203.02	211	221.02	234	259.14	279.81	298.41	331.45	372.01	541.35
04/10/2017	14:57:19	125.47	115.53	194.82	329.48	107.92	124.36	203.66	140.55	124.36	44.75	148.24	132.87	0.4014	0.3862	110.96	115.53	120.22	125.12	130.5	136.75	145.46	162.59	185.78	194.82	202.77	210.63	220.32	232.72	257.2	278.99	296.4	329.48	371.6	541.35
04/10/2017	14:57:26	133.27	115.49	194.6	329.79	107.96	124.31	203.41	140.41	124.31	44.6	148.07	132.74	0.4012	0.3865	110.94	115.49	120.12	124.96	130.32	136.48	144.9	161.17	185.2	194.6	202.39	210.31	219.81	232.1	255.92	278.36	296.39	329.79	372.31	541.35
04/10/2017	14:57:34	141.07	115.44	194.2	329.59	107.97	124.3	203.02	140.25	124.3	44.39	147.92	132.59	0.4013	0.3869	110.96	115.44	120.02	124.86	130.12	136.14	144.45	159.58	184.66	194.2	201.91	209.83	219.08	231.24	254.38	277.3	296.03	329.59	372.86	541.35
04/10/2017	14:57:42	148.88	115.3	193.56	326.7	107.88	124.16	202.6	140.02	124.16	44.21	147.68	132.37	0.4014	0.3869	110.89	115.3	119.89	124.64	129.86	135.79	143.95	158.21	184	193.56	201.57	209.45	218.71	230.74	253.47	277.11	295.8	326.7	372.27	541.35
04/10/2017	14:57:50	156.68	115.29	193.19	326.44	107.9	124.16	202.52	139.9	124.16	44.07	147.55	132.26	0.4014	0.3867	110.85	115.29	119.86	124.56	129.68	135.53	143.52	156.98	183.27	193.19	201.5	209.39	218.56	230.49	252.66	276.53	295.37	326.44	371.61	541.35
04/10/2017	14:57:56	163.23	115.26	193.08	325.26	107.85	124.09	202.38	139.76	124.09	43.94	147.39	132.14	0.4011	0.3872	110.8	115.26	119.78	124.44	129.48	135.28	143.19	156.09	182.81	193.08	201.31	209.28	218.24	230.33	251.96	275.17	294.59	325.26	371.34	541.35
04/10/2017	14:58:04	170.97	115.26	193.45	326.98	107.87	123.95	202.5	139.73	123.95	44.05	147.36	132.1	0.4011	0.3875	110.83	115.26	119.73	124.34	129.37	135.22	143.24	156.31	182.94	193.45	201.68	209.73	218.69	230.86	254.45	276.67	295.75	326.98	372.3	541.35
04/10/2017	14:58:12	178.79	115.18	193.05	326.32	107.88	123.9	202.38	139.58	123.9	43.85	147.19	131.98	0.4006	0.3879	110.81	115.18	119.6	124.18	129.16	134.96	142.83	155.2	182.17	193.05	201.4	209.31	218.19	230.12	252.44	275.19	294.49	326.32	371.7	541.35
04/10/2017	14:58:20	186.59	115.1	192.9	326.7	107.91	123.81	202.25	139.44	123.81	43.76	147.02	131.85	0.4003	0.3885	110.78	115.1	119.47	124.01	129.02	134.8	142.56	154.33	181.66	192.9	201.31	209.28	217.95	230.04	252.17	274.73	294.43	326.7	371.92	541.35
04/10/2017	14:58:28	194.41	115	192.31	324.18	107.95	123.72	202.06	139.28	123.72	43.52	146.87	131.7	0.4004	0.3881	110.75	115	119.32	123.82	128.8	134.6	142.05	153.31	180.69	192.31	200.95	208.83	217.3	229.27	250.34	273.05	292.62	324.18	368.04	480.5
04/10/2017	14:58:35	202.23	114.96	192	322.08	107.99	123.7	201.92	139.18	123.7	43.34	146.75	131.61	0.4001	0.3879	110.73	114.96	119.28	123.74	128.66	134.36	141.57	152.51	180.03	192	200.56	208.59	216.97	229.12	249.69	271.95	291.22	322.08	365.07	480.5
04/10/2017	14:58:43	210	114.93	191.75	319.57	107.98	123.67	201.93	139.1	123.67	43.22	146.64	131.55	0.3997	0.3875	110.71	114.93	119.24	123.65	128.55	134.2	141.31	152.06	179.36	191.75	200.38	208.46	216.65	228.35	248.81	270.56	290.52	319.57	365.04	480.5
04/10/2017	14:58:51	217.8	114.9	191.4	316	108.02	123.6	201.92	139.01	123.6	43.04	146.54	131.47	0.3996	0.3873	110.67	114.9	119.17	123.52	128.42	134.03	141.01	151.54	178.58	191.4	200.14	208.21	216.2	227.27	248.02	269.42	289.38	316	364.36	470.43
04/10/2017	14:58:59	225.6	114.88	191.06	316.34	108.02	123.56	201.66	138.88	123.56	42.94	146.41	131.35	0.3996	0.3866	110.64	114.88	119.12	123.43	128.29	133.82	140.72	151.04	177.46	191.06	199.9	207.93	216.2	227.23	247.5	269.02	289.44	316.34	364.42	480.28

Innopharma technology

HORIBA Scientific

EyePASS Version 3.0

Machine learning image analysis

EyePASS

Innopharma technology

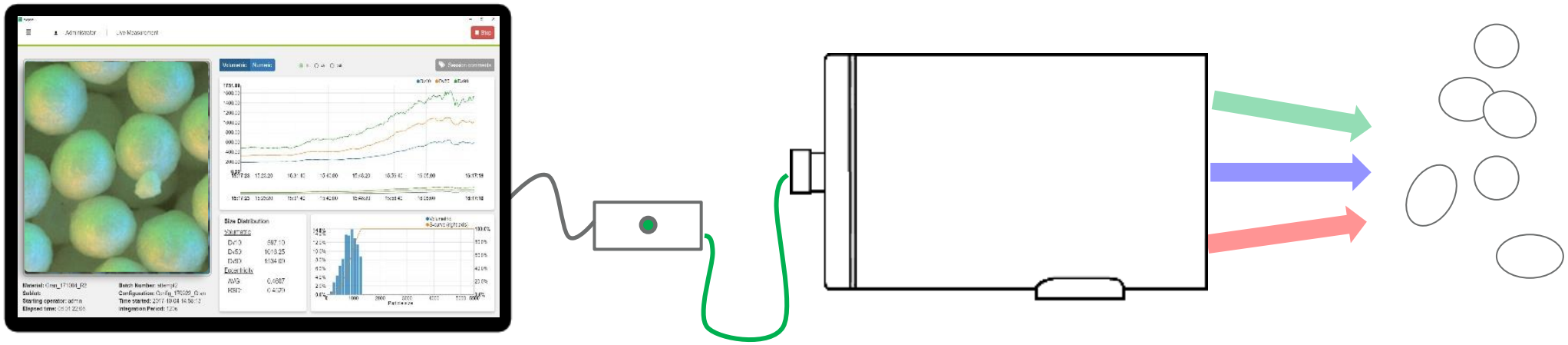
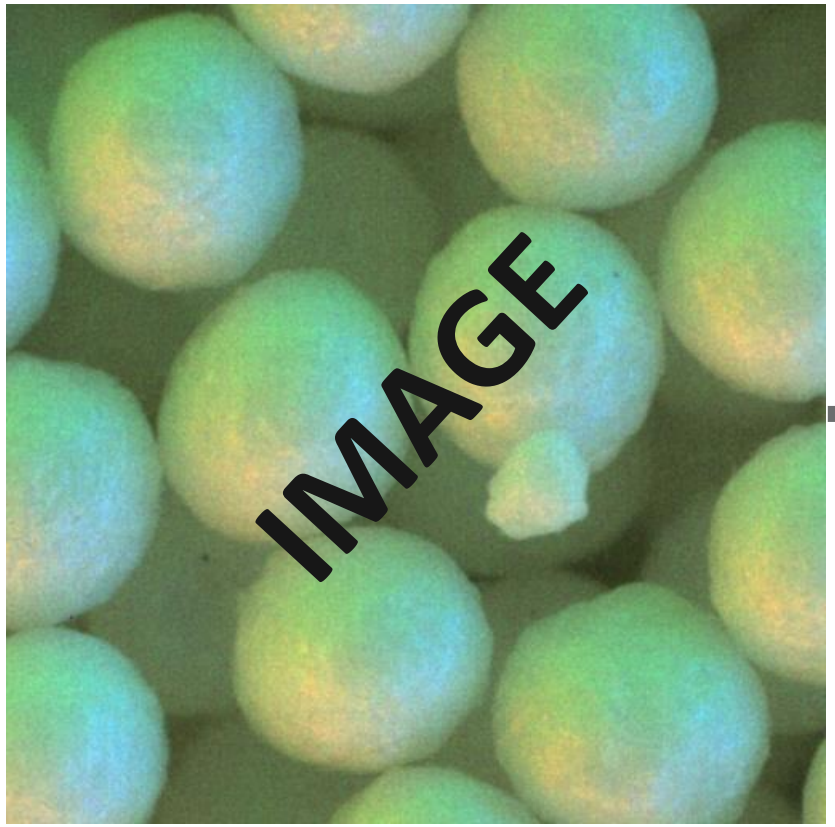


Image Analysis

Image Acquisition

What is Image Analysis?

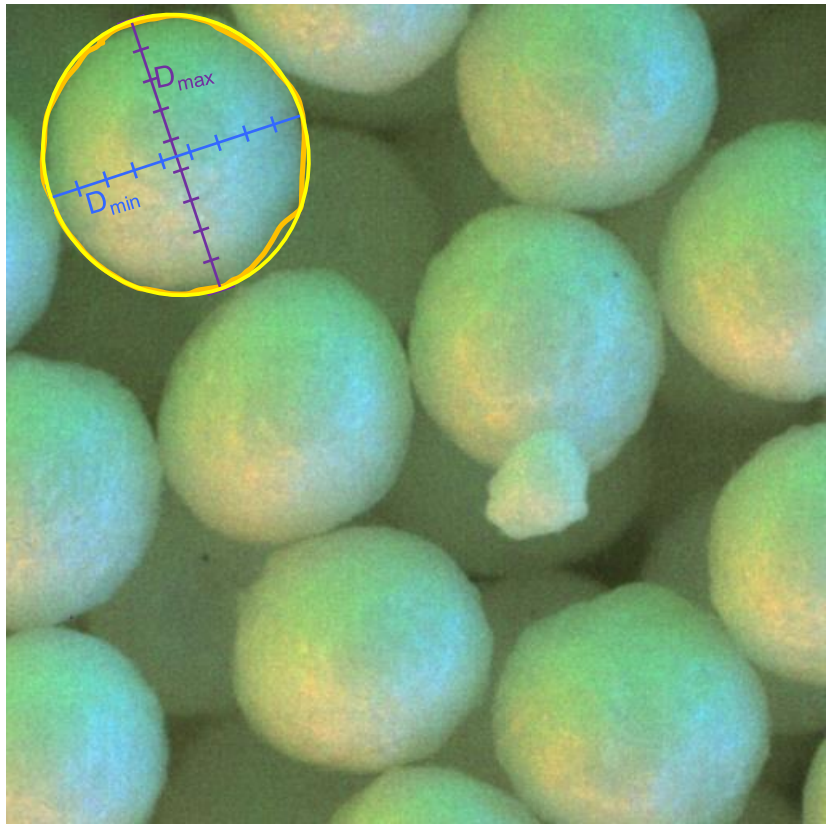


Analysis

D_{min}	D_{max}
1046.2	1078.89
1061.42	1138.09
1147.19	1336.78
1659.39	[illegible]62
840.353	[illegible]1.95
1065.6[illegible]	1133.62
9[illegible].2[illegible]	1140.41
1049.12	1151.69
943.567	1142.3
980.434	1178.46
914.148	1095.72

DATA

What does it involve?



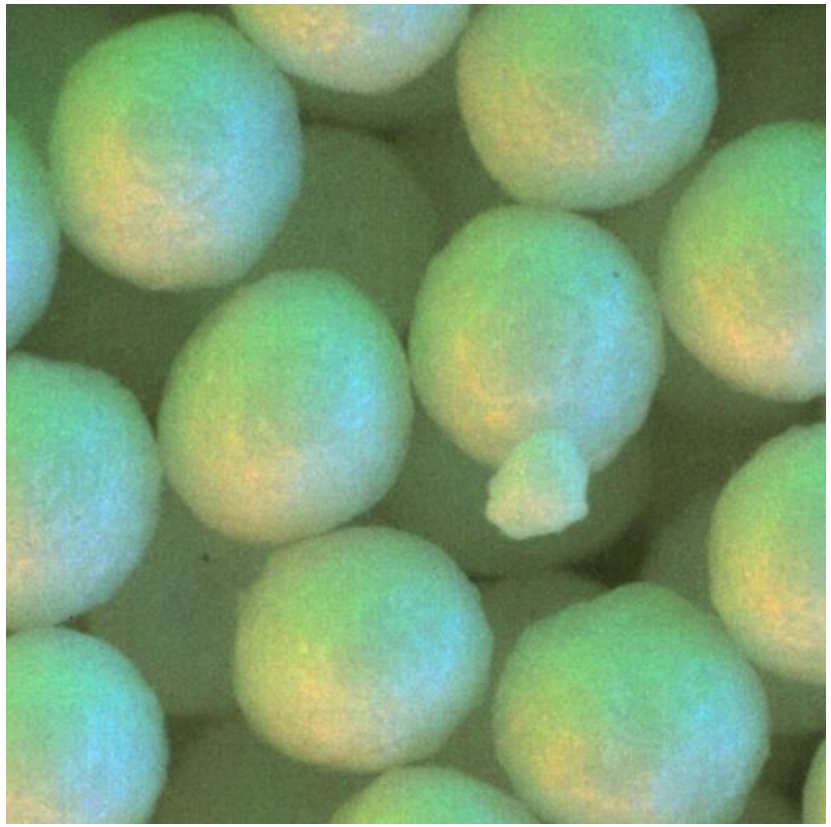
Vision Task

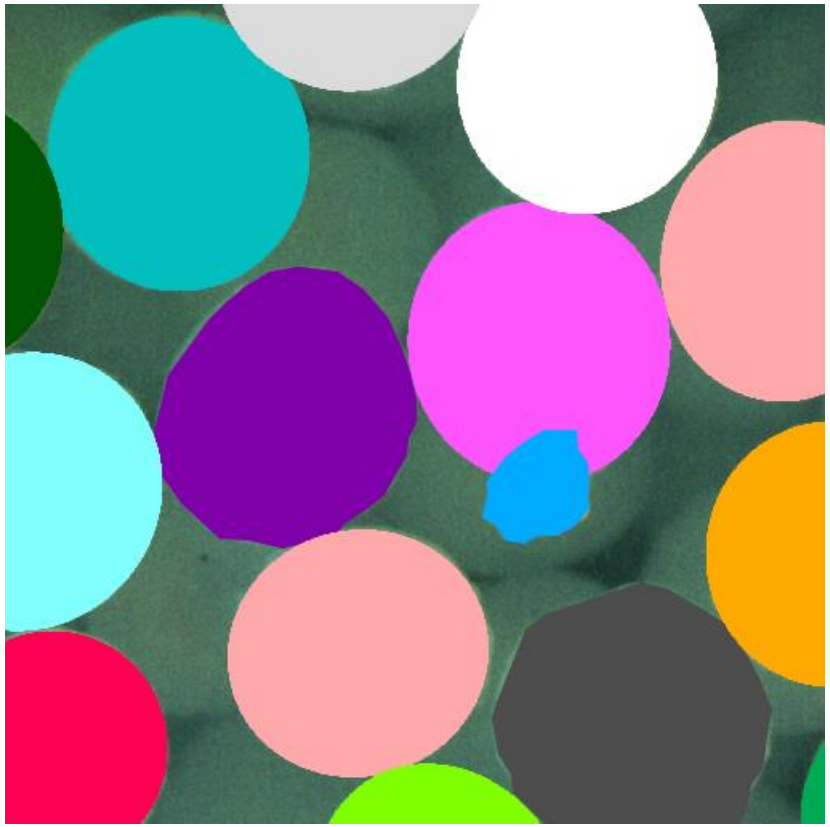
Delineate objects of interest
e.g., particles

Measurement Task

Measure necessary attributes of each object
e.g., major/minor axes lengths

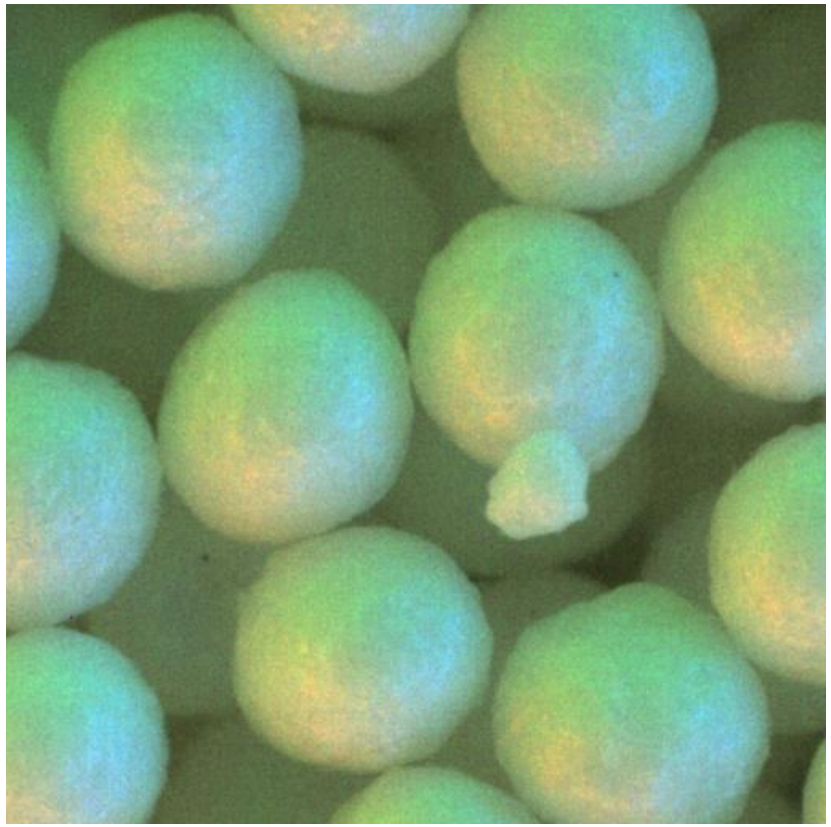
Image Segmentation

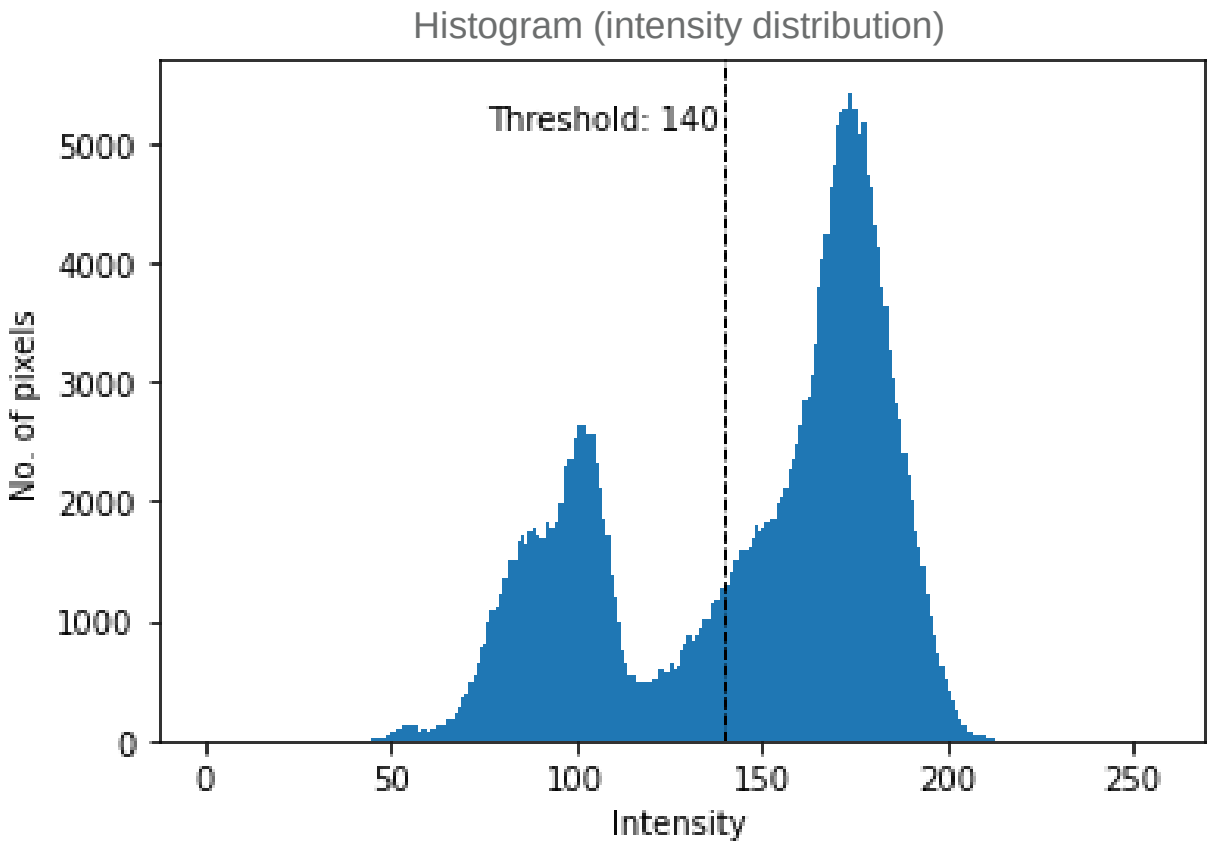




The goal as defined by a human observer

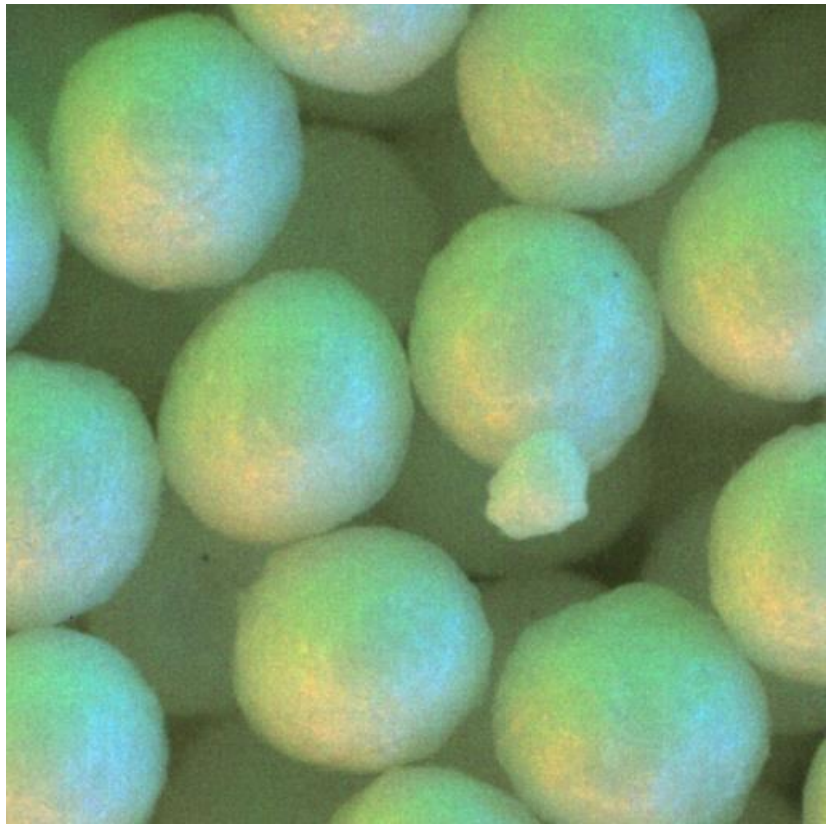
Image Segmentation

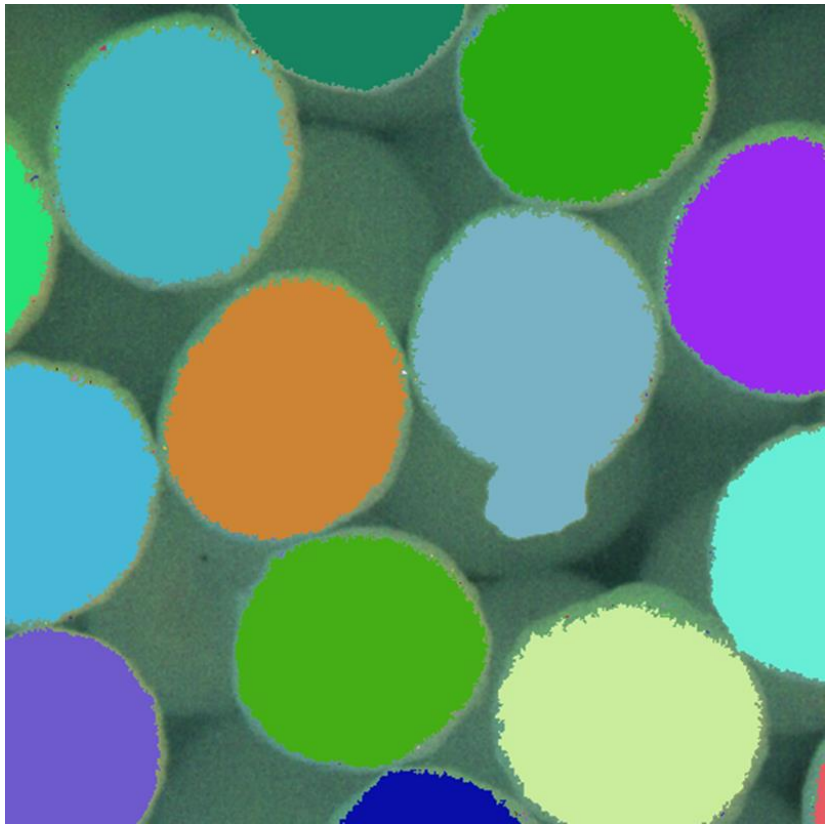




Classical Image Processing - Thresholding

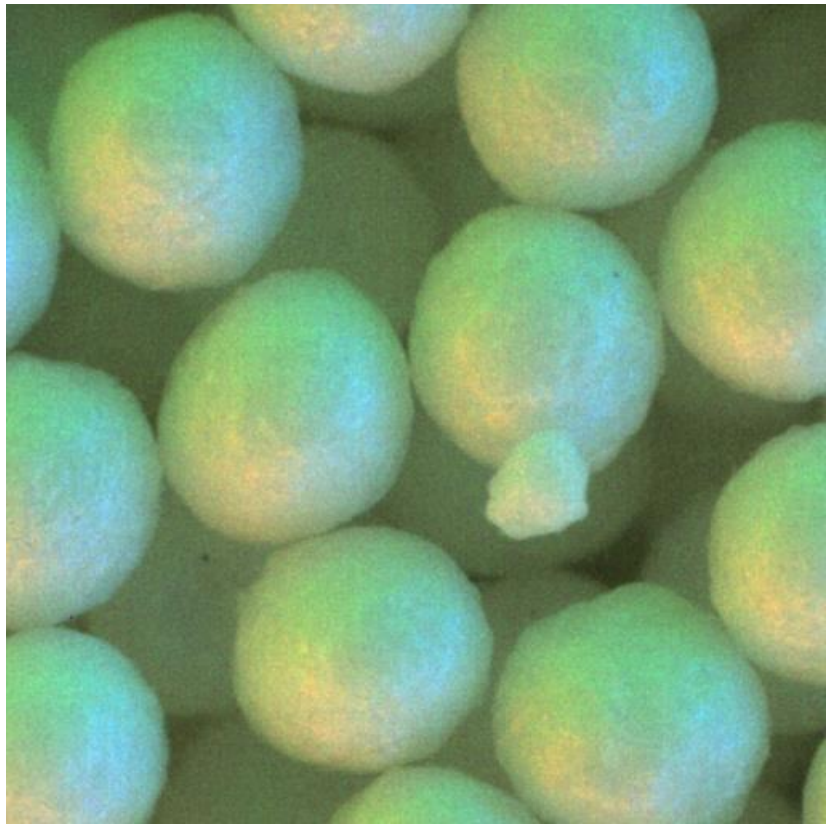
Image Segmentation



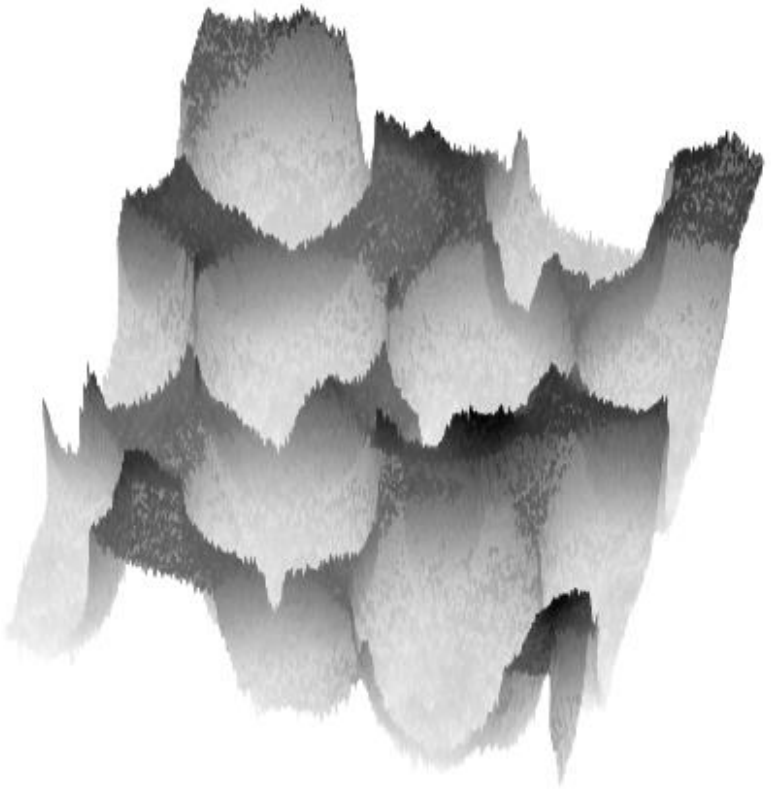


Classical Image Processing - Thresholding

Image Segmentation

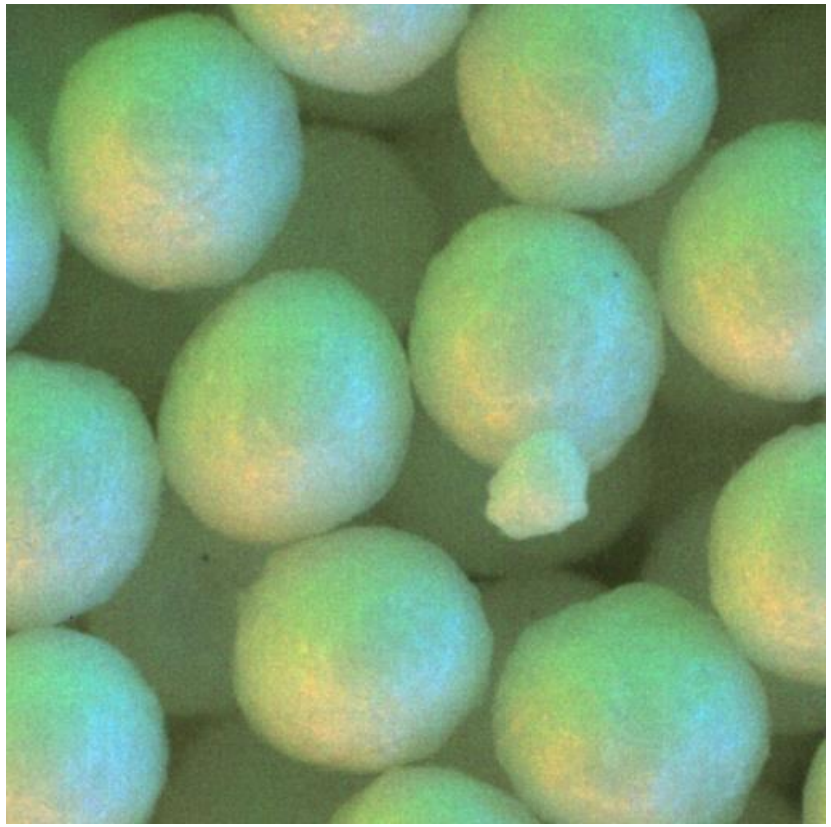


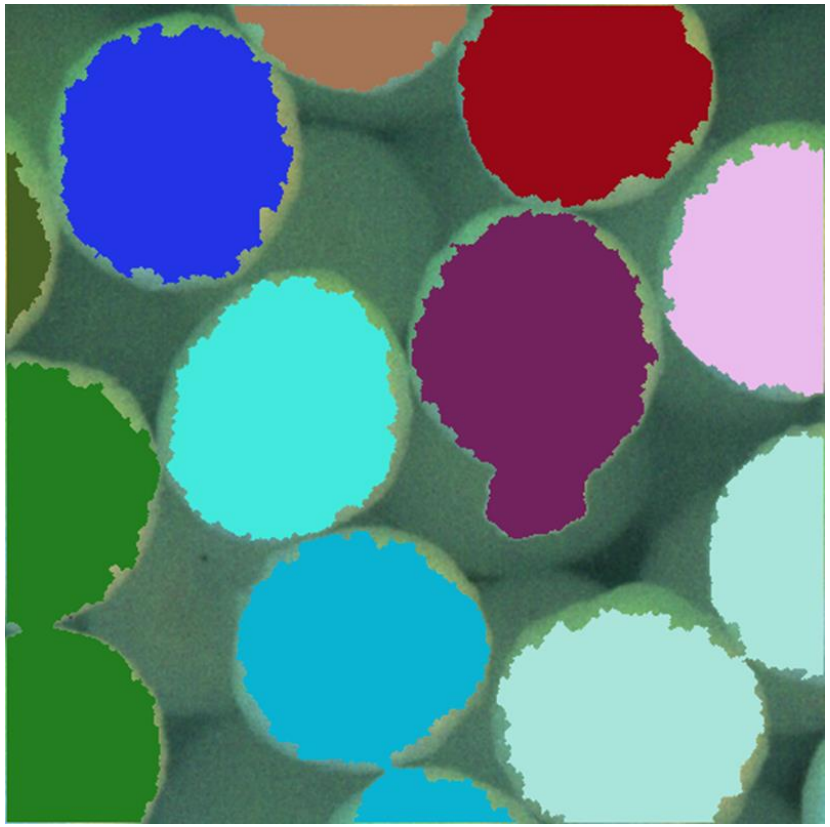
Surface Plot



Classical Image Processing - Watershed

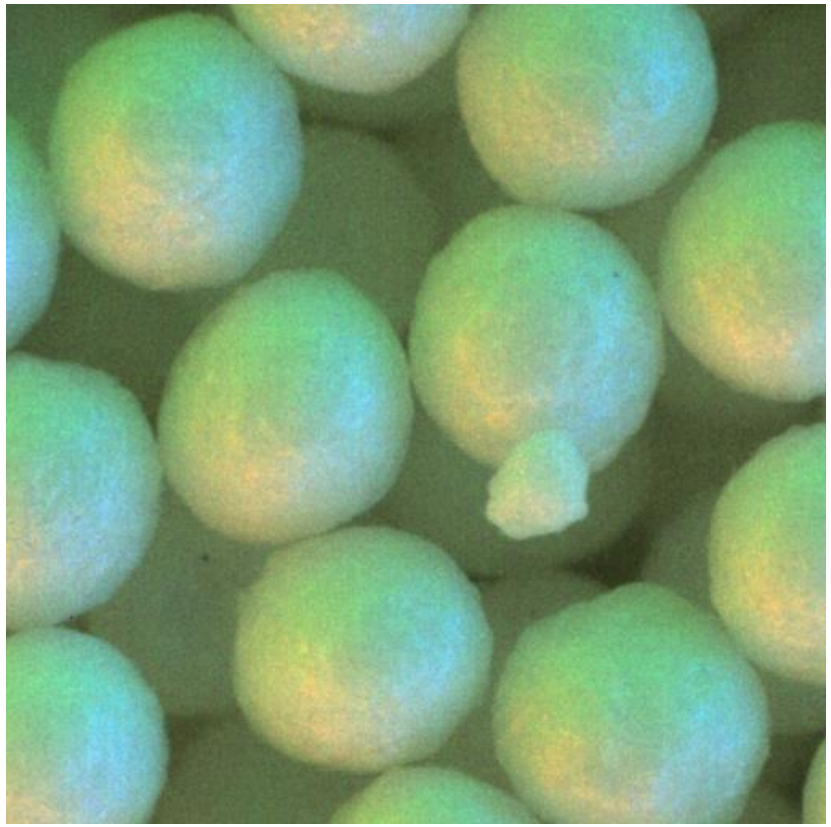
Image Segmentation

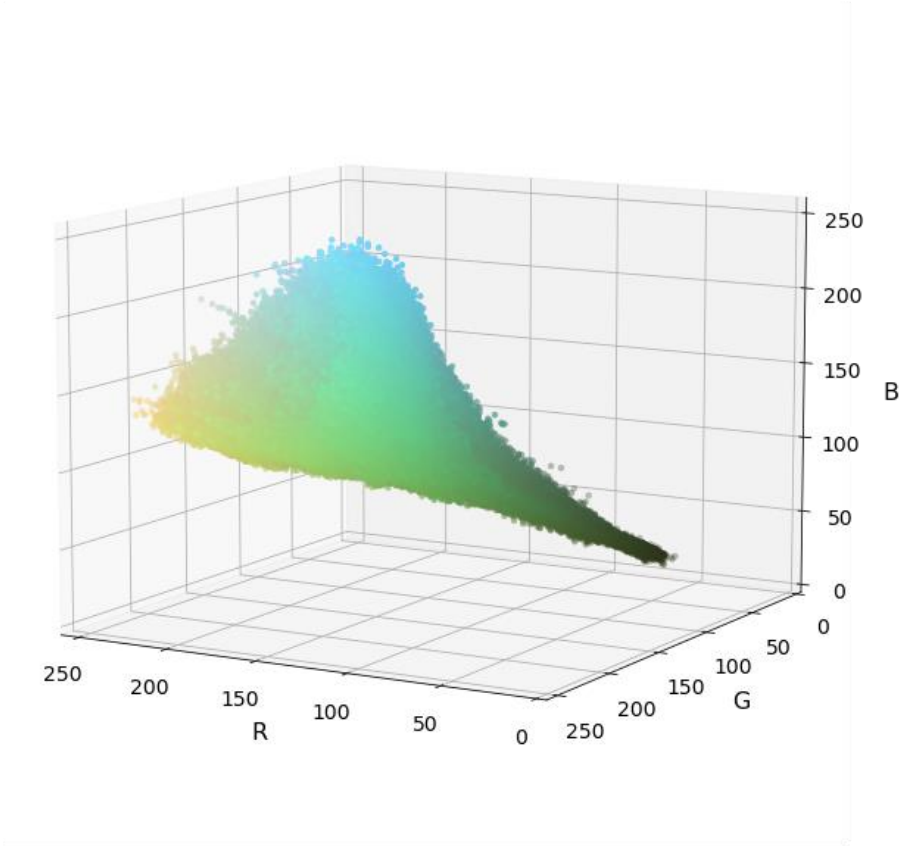




Classical Image Processing - Watershed

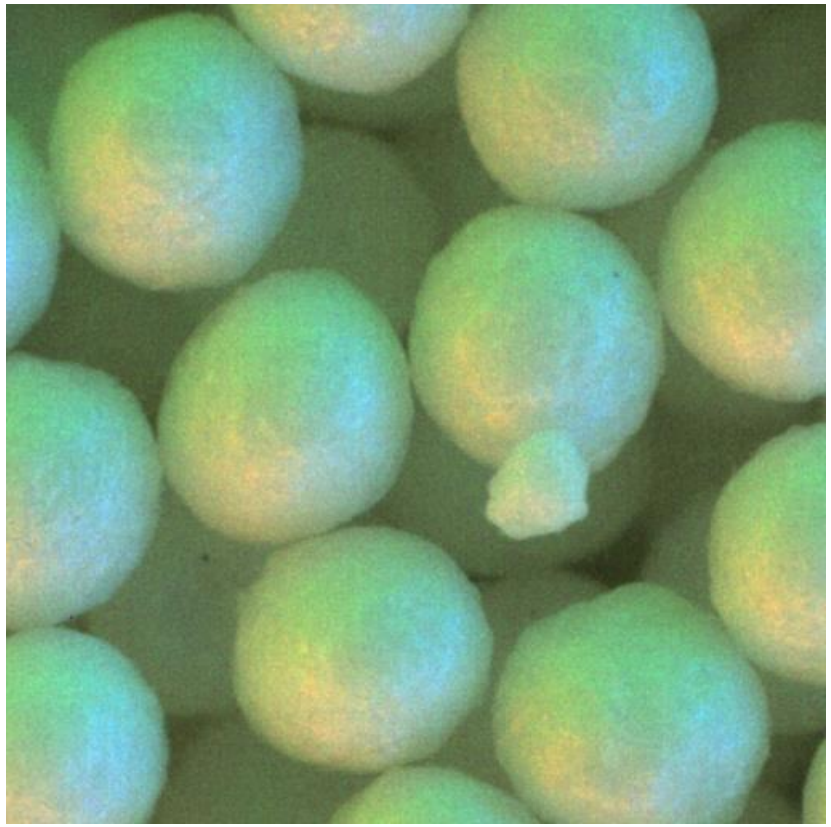
Image Segmentation





Machine Learning - Clustering

Image Segmentation



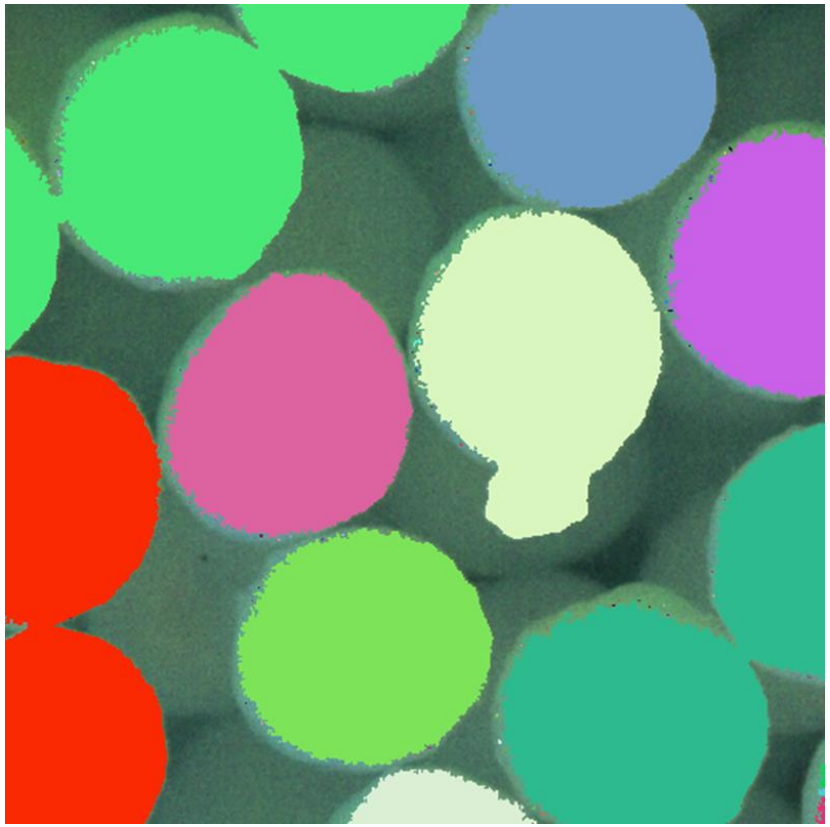
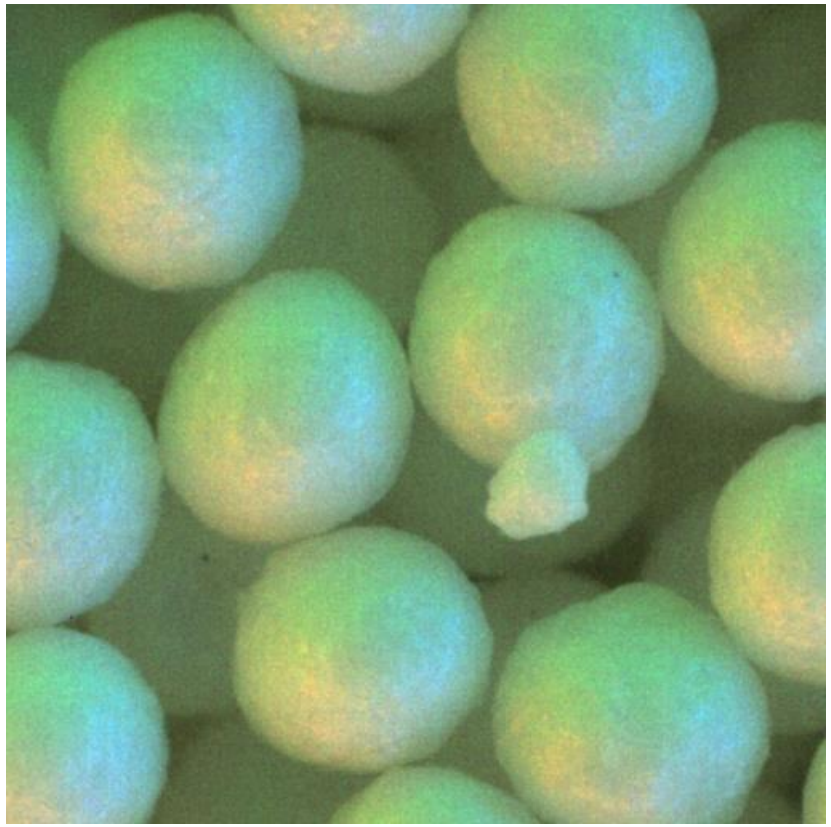
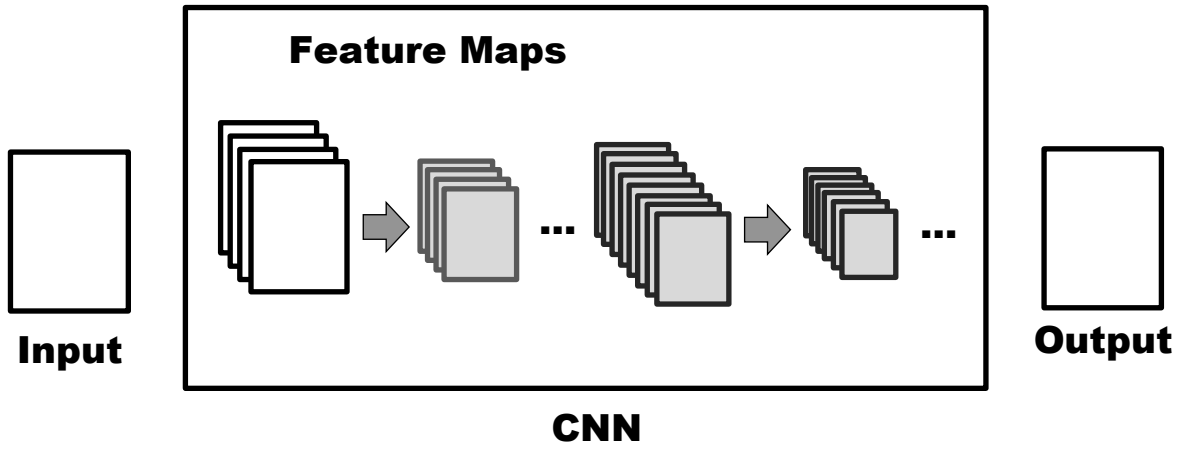


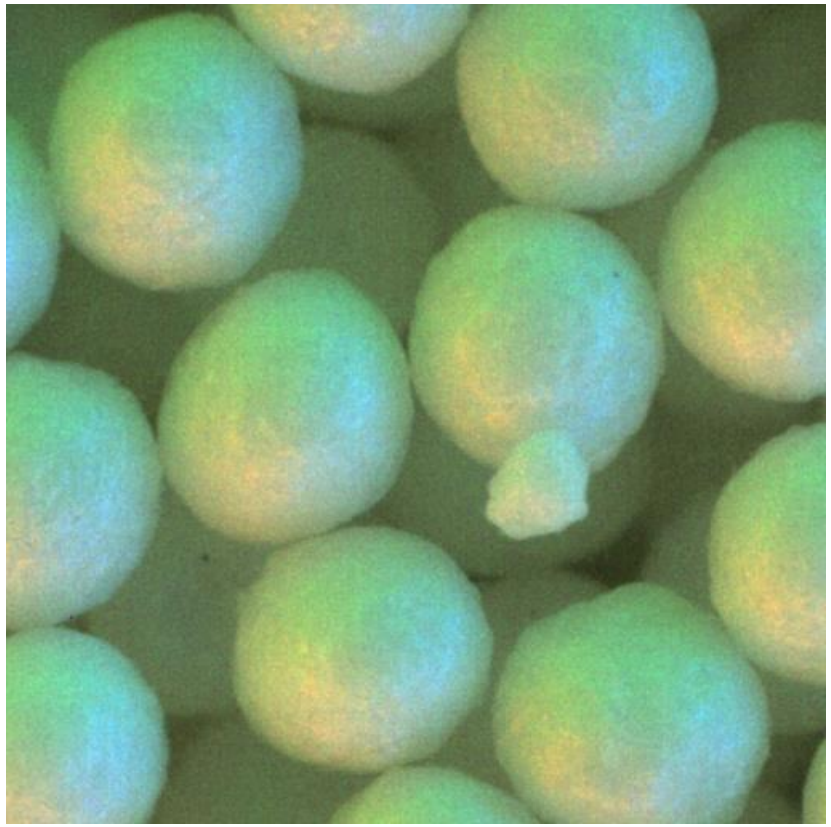
Image Segmentation

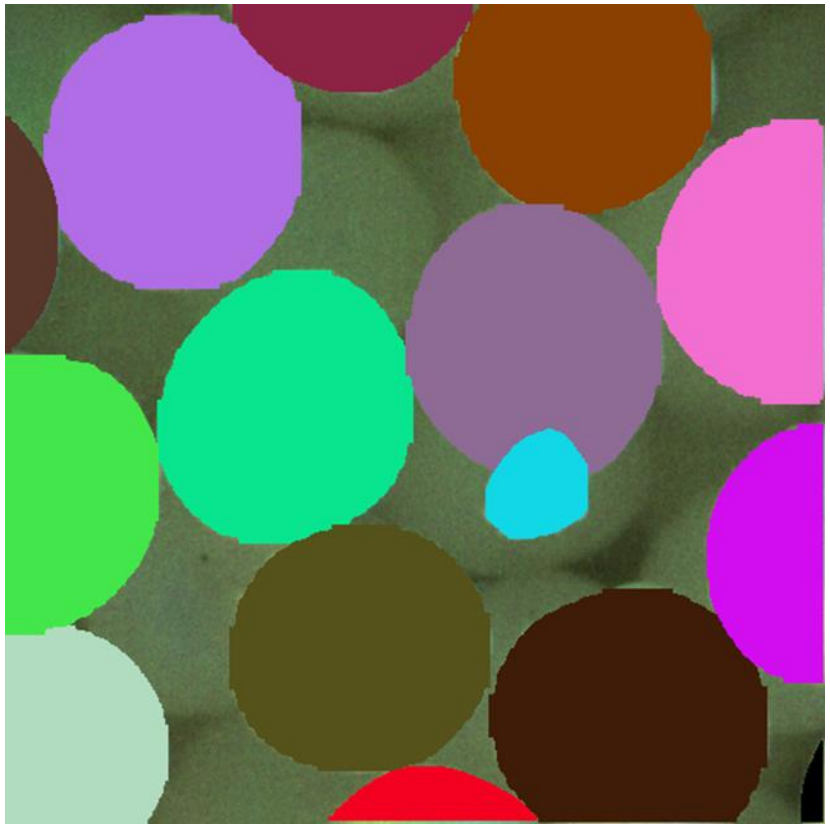




Machine Learning - Convolutional Neural Networks (CNNs)

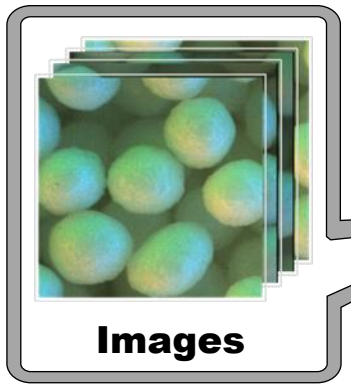
Image Segmentation





Machine Learning - Convolutional Neural Networks (CNNs)

Classical Image Processing



Pre-processing
- Contrast Enhancement
- Noise Reduction
- Colour Transformations

etc

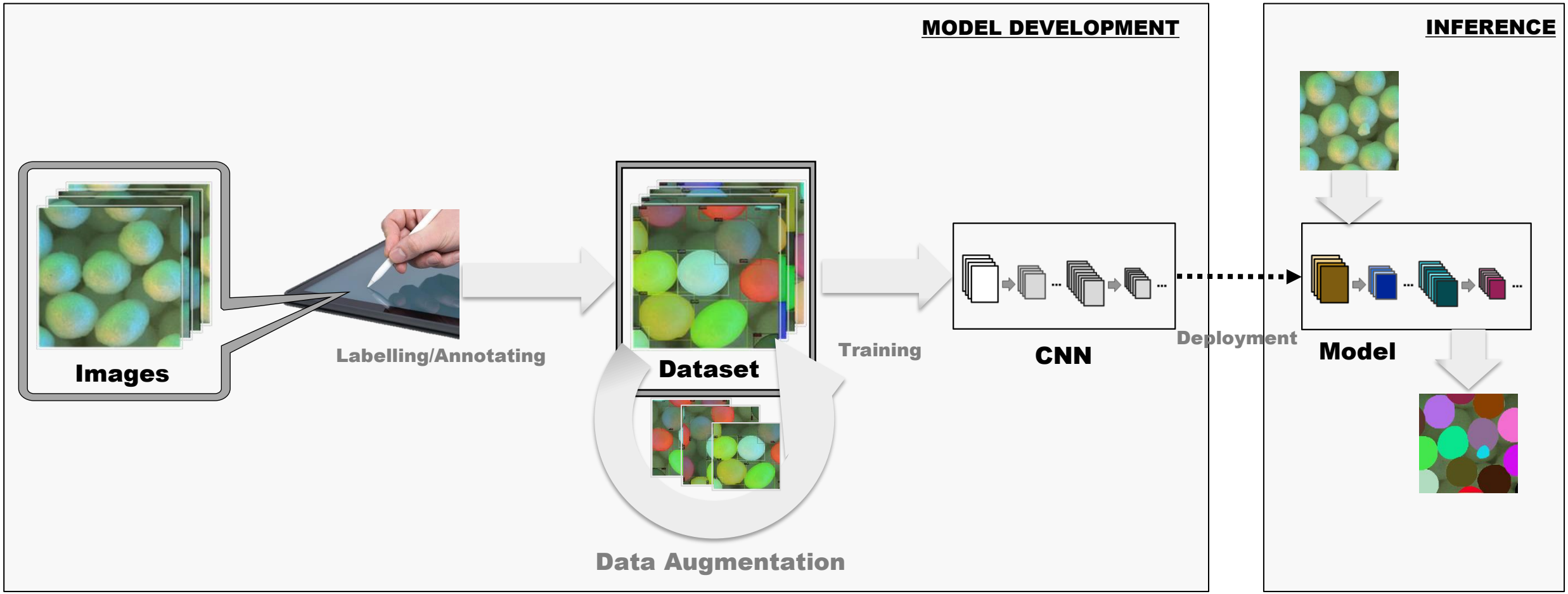
Segmentation
- Thresholding
- Watershed

etc

Post-processing
- Size-based Region Selection
- Region Merging

etc

Convolutional Neural Networks



Model Development Process - K-fold cross validation

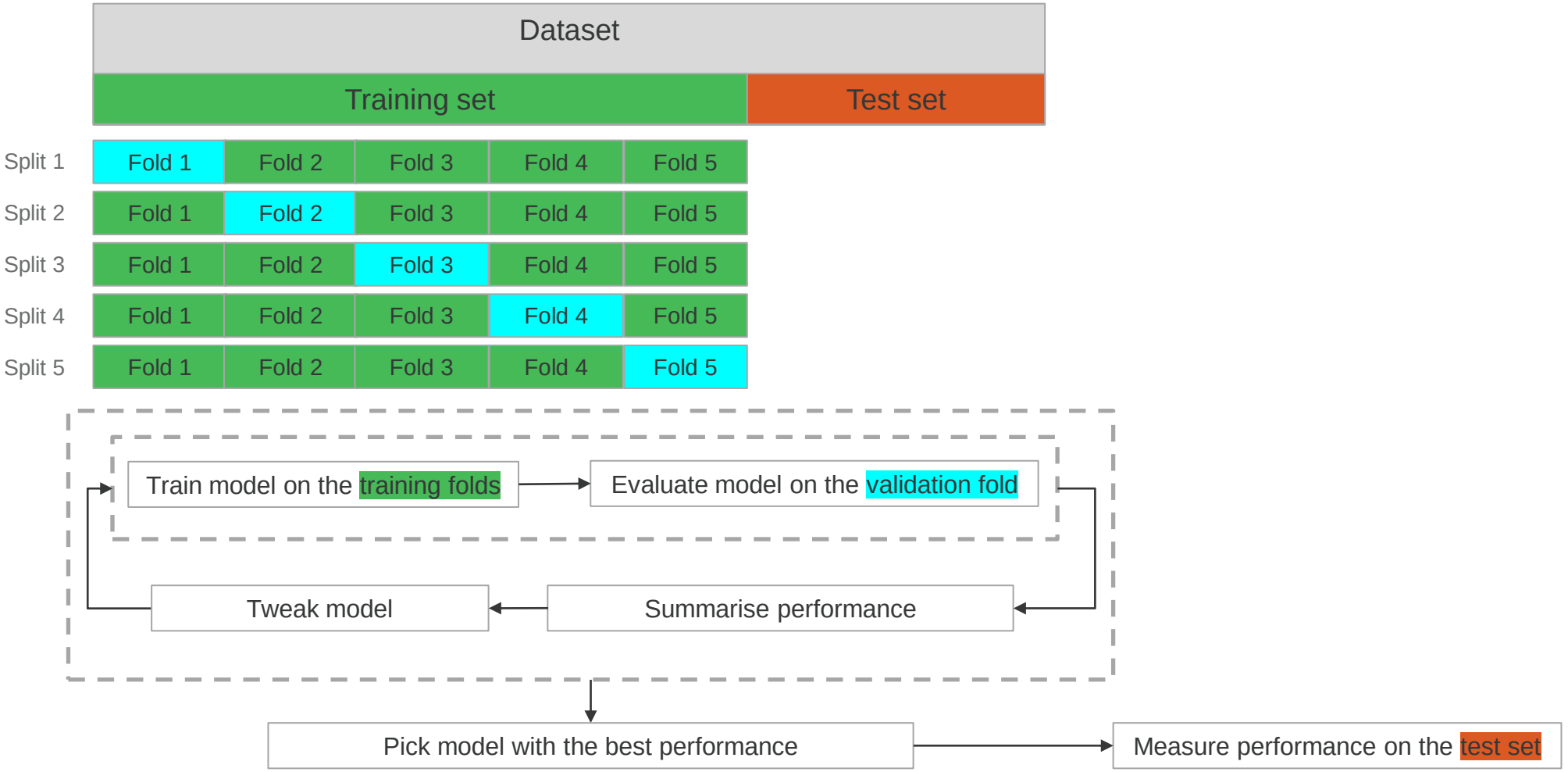
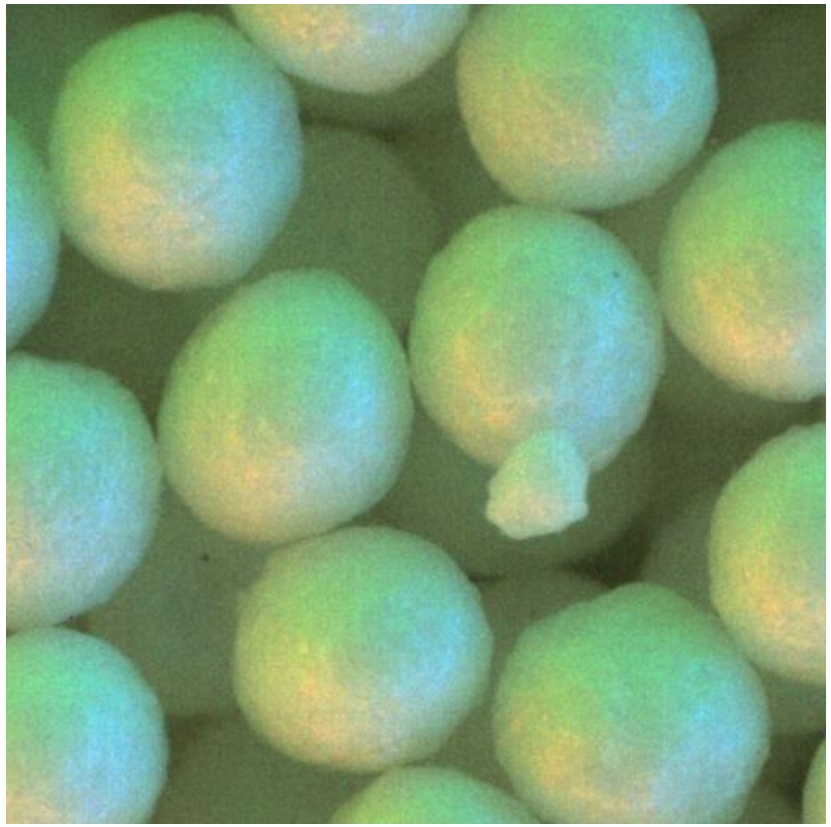


Image Segmentation

In EyePASS v2…



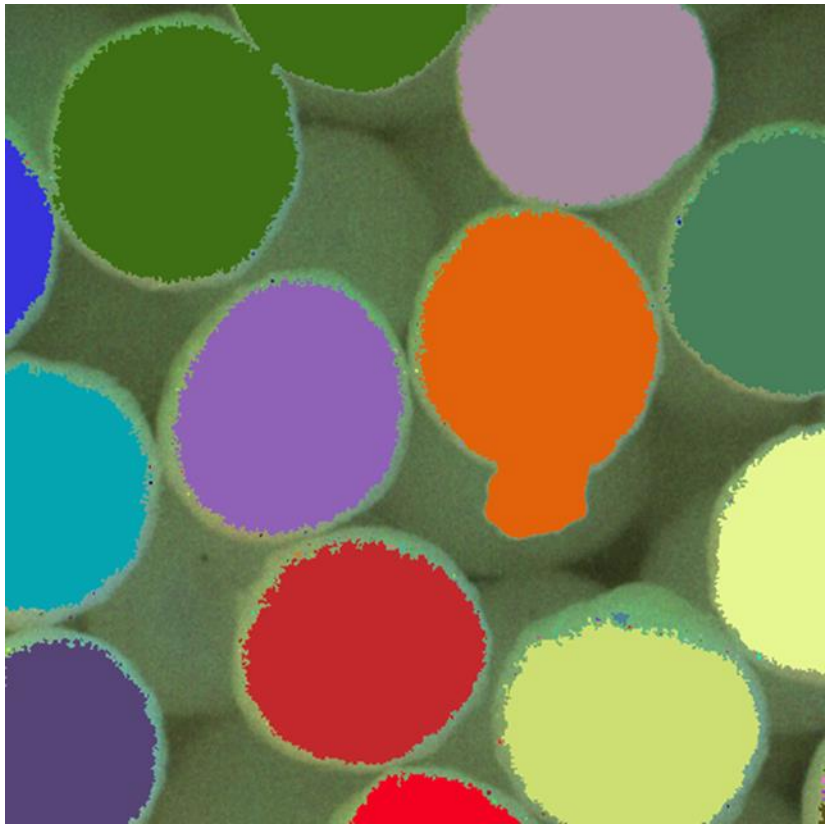
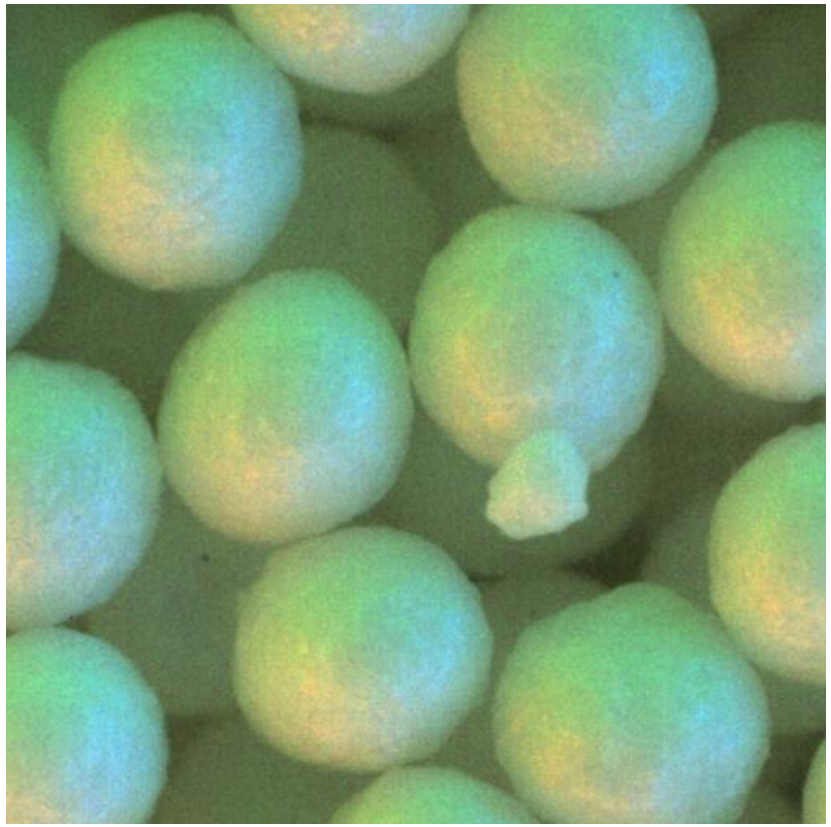
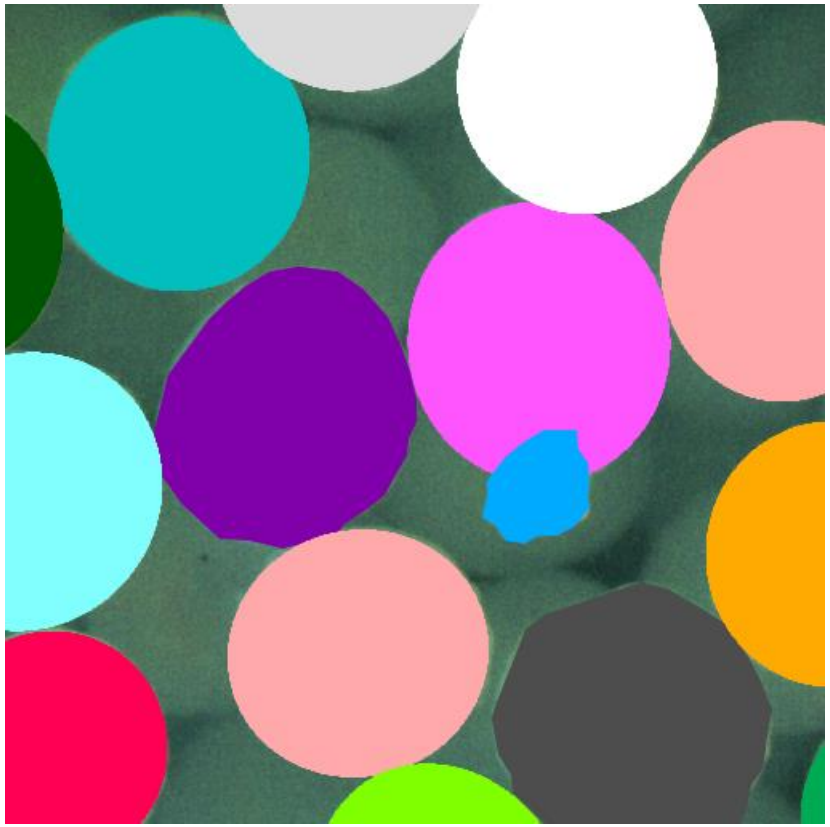


Image Segmentation

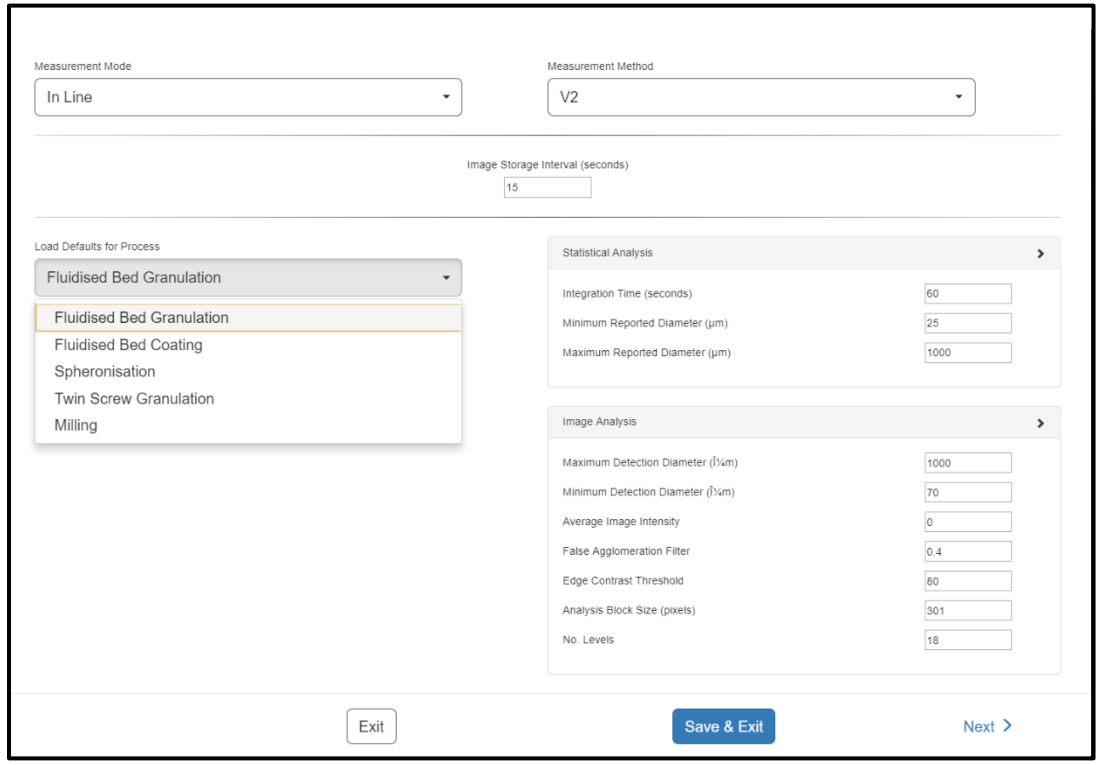
…compared to EyePASS v3



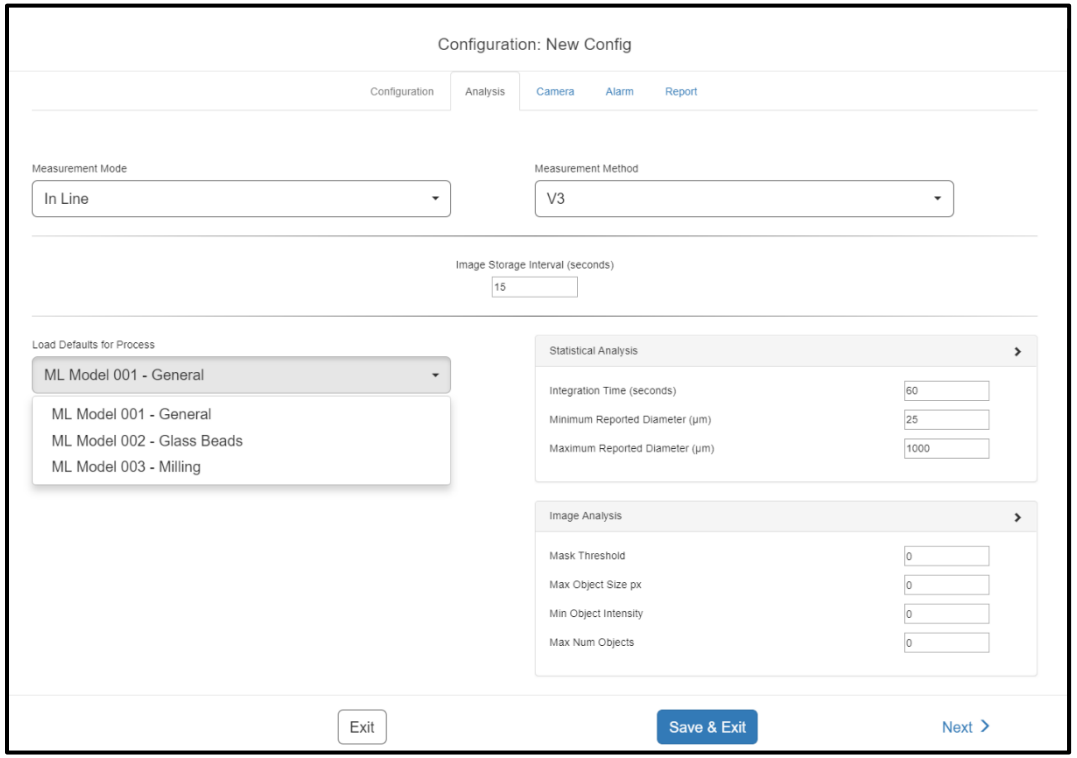


User Experience

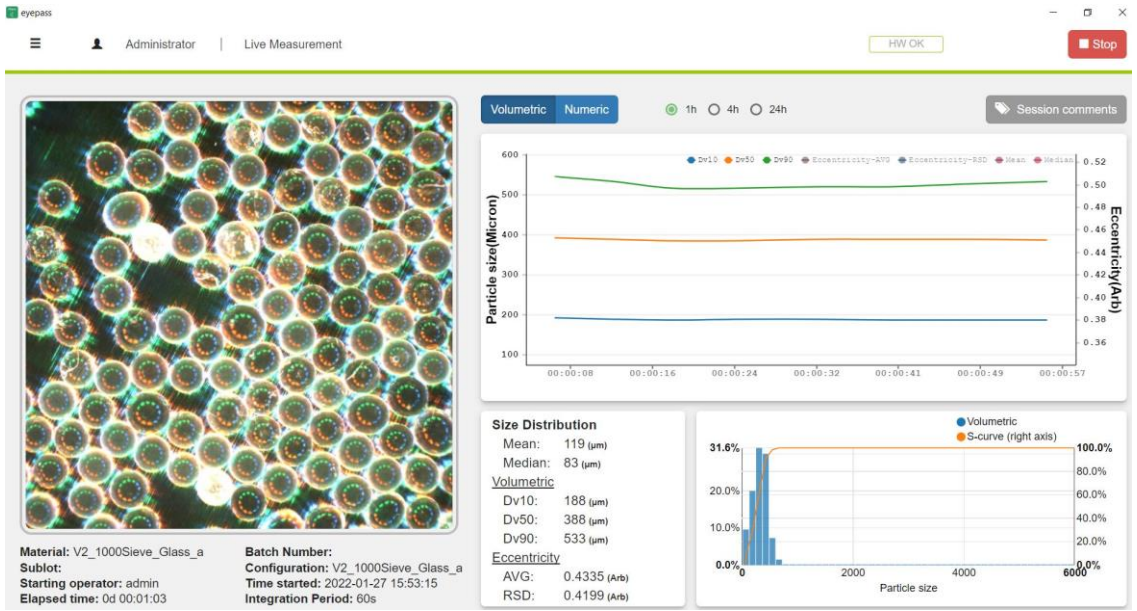
EyePASS V2.0

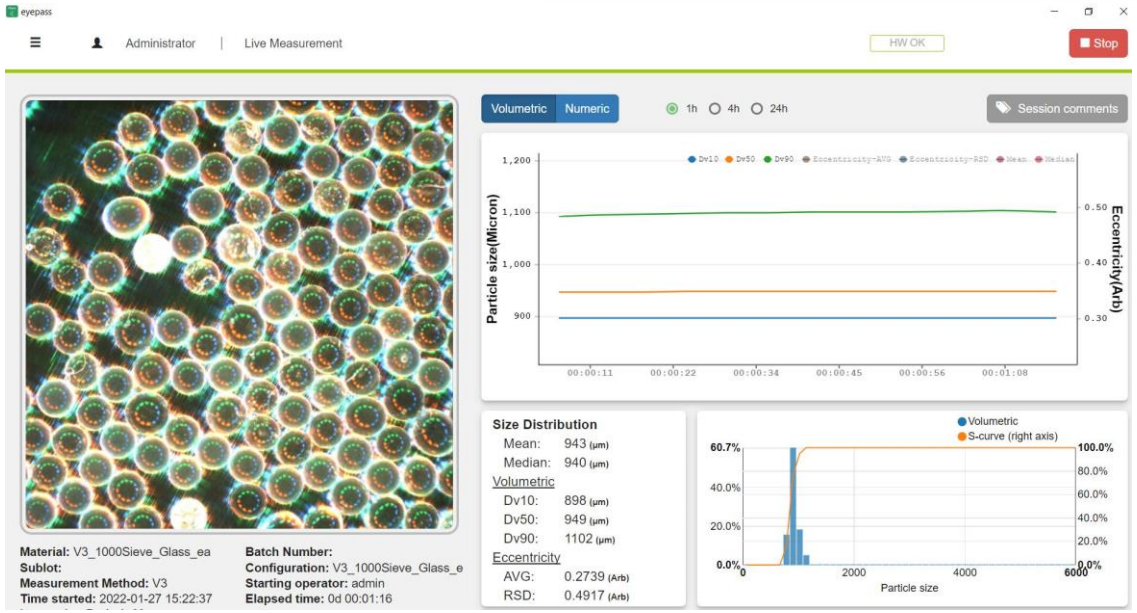


EyePASS V3.0

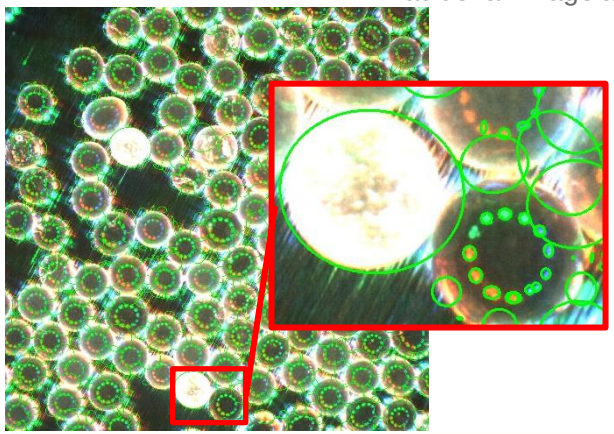


EyePASS - Before and After Machine Learning





Traditional Image analysis

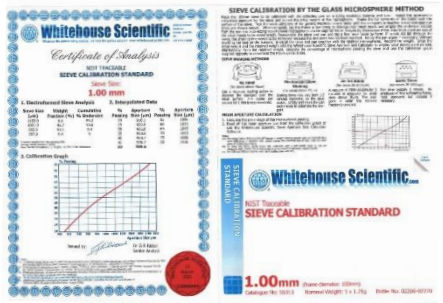


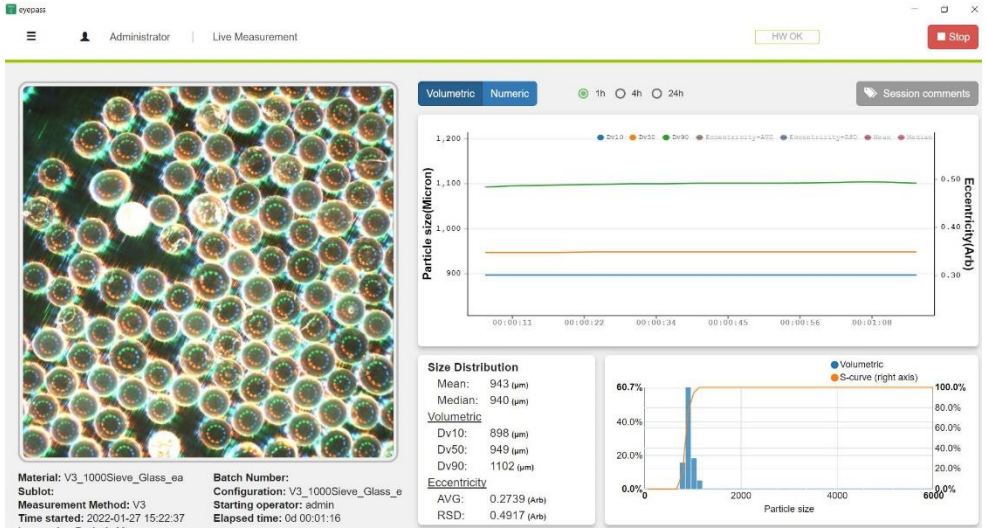
Dv10: 188 (µm)
Dv50: 388 (µm)
Dv90: 533 (µm)

Machine Learning Image analysis

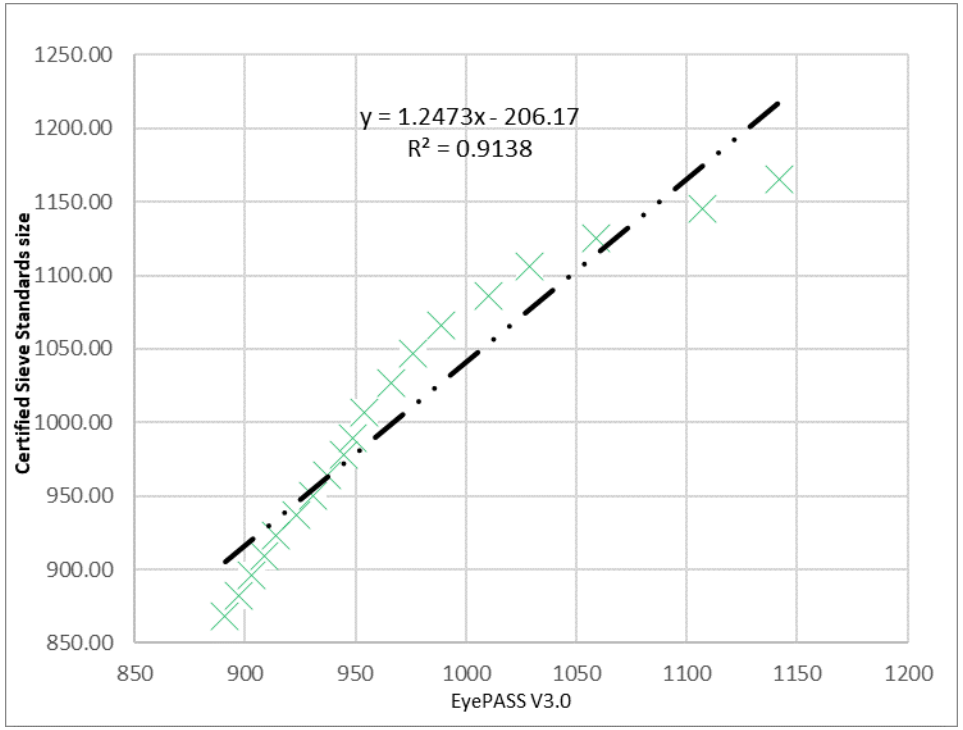
Dv10: 898 (µm)
Dv50: 949 (µm)
Dv90: 1102 (µm)

EyePASS V3.0 - Results



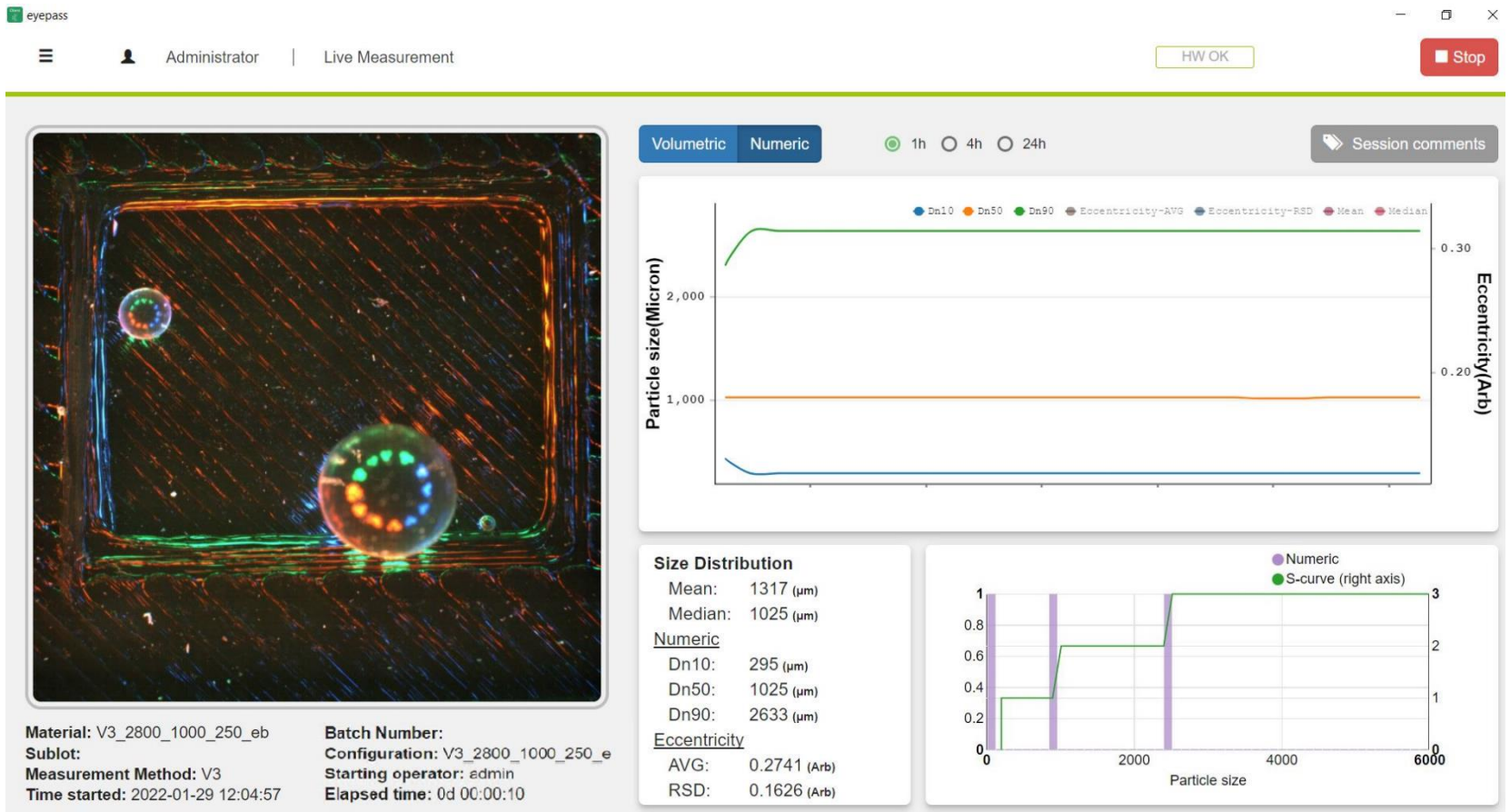


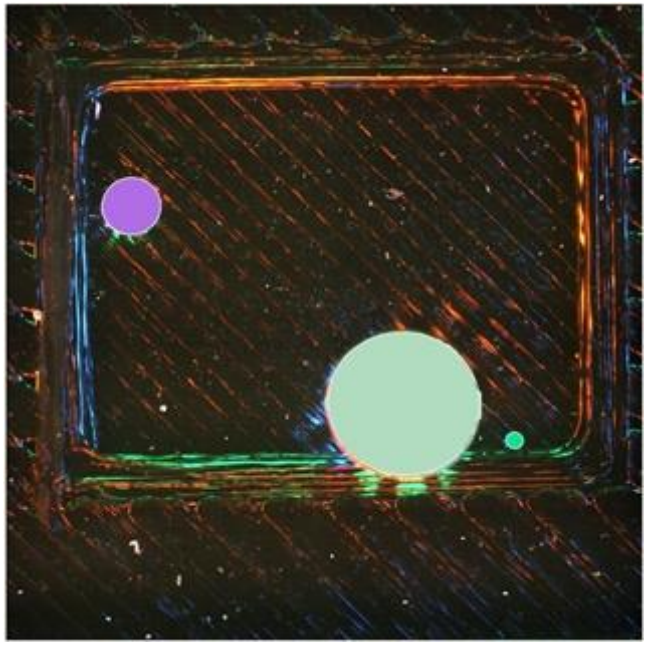
1000um	Glass Sieve Std um	EyePASS V3.0 (Sub sample) um	um diff	% diff
D10	882.1	898	15	2%
D50	989.6	949	41	4%
D90	1145.6	1102	39	3%



Correlation of 0.9559 = Strong Positive

Untapped Potential



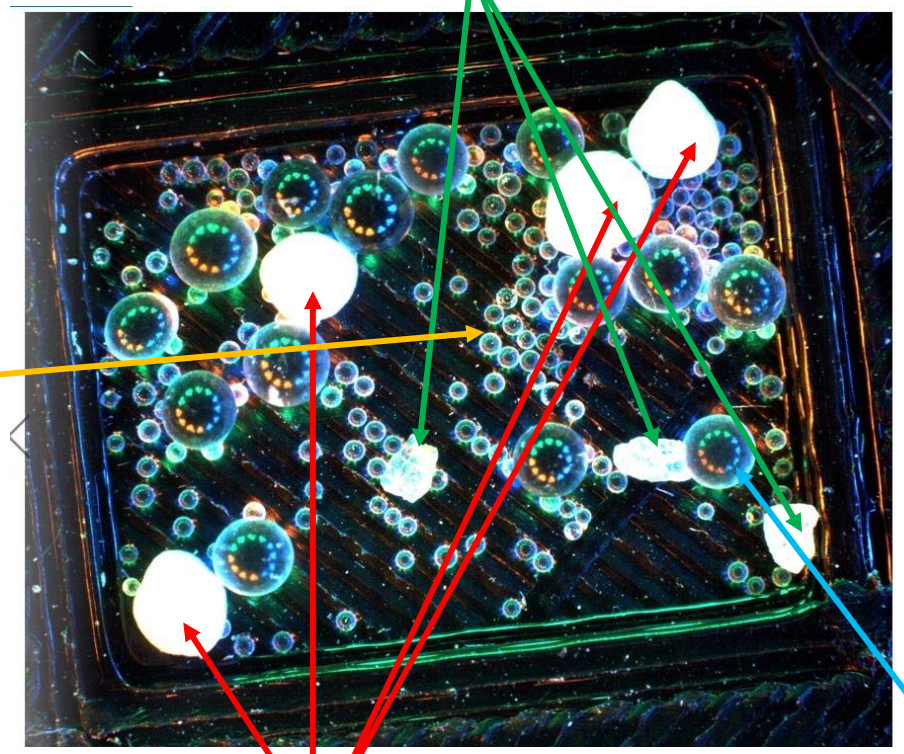


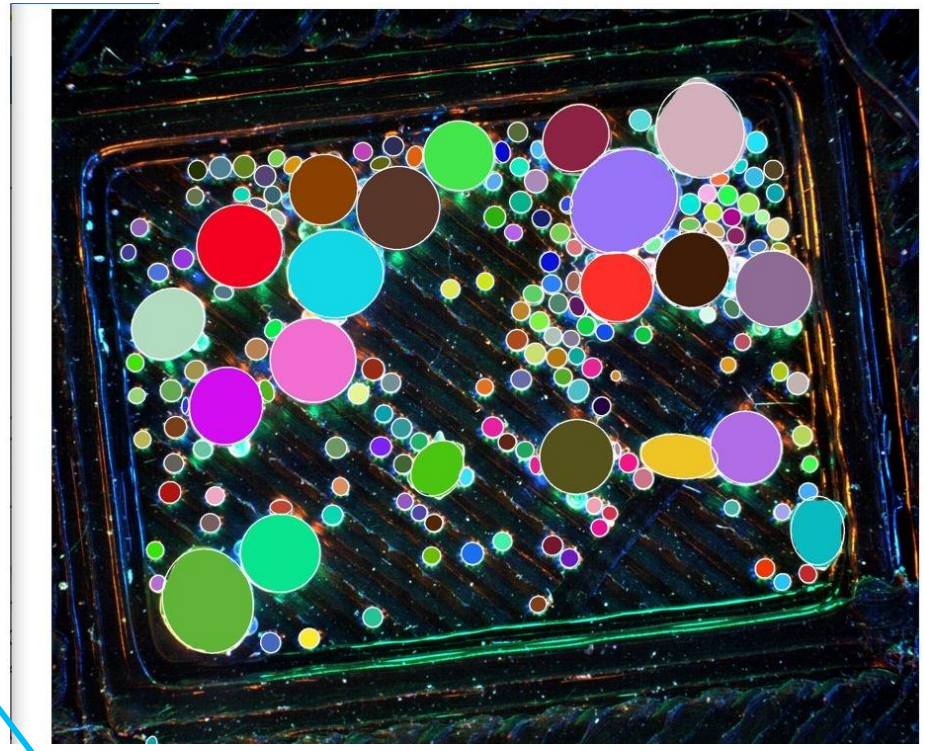
Inspiring Capability

4 materials
ML
mitigates issues
like false
detections

500um Alu Oxide
(Bonded Abrasives)

250um Glass Microspheres
(Sieve Calibration Standard)

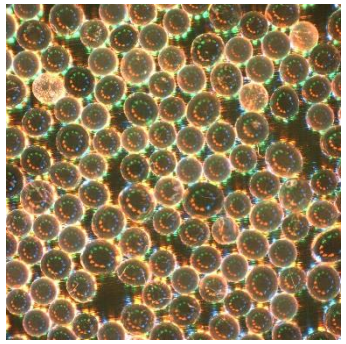




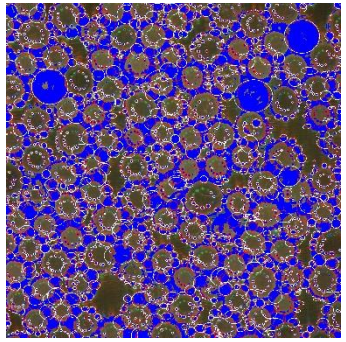
1000um Multiparticulates
(Wurster materials, cellets, suglets)

1000um Glass Microspheres
(Sieve Calibration Standard)

The Power of Machine Learning

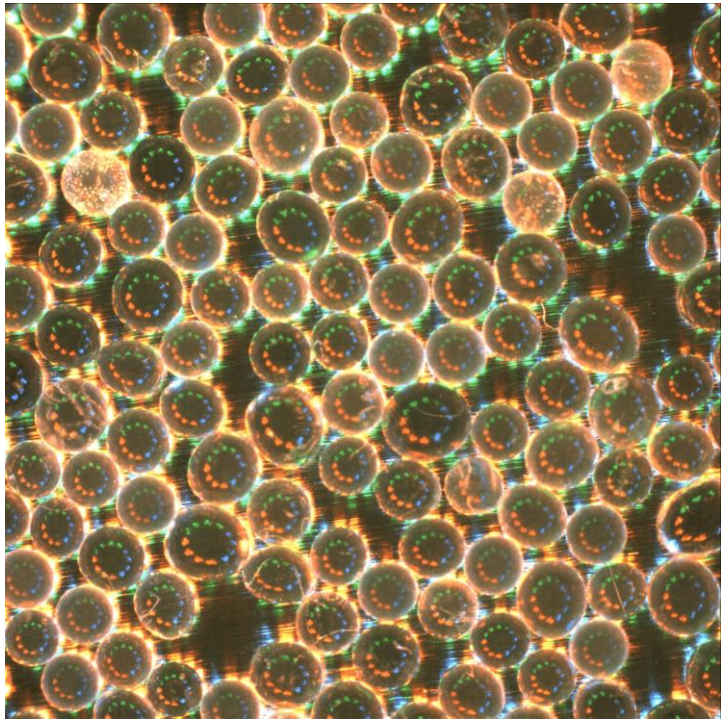


Eyecon$_2$ Image



EyePASS V2.0

EyePASS V3.0



Thank you!

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Senior Software Developer
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