Quartz Detector Trained in Nvidia DIGITS using AlexNet

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Abstract

This paper presents a novel use of AlexNet, a deep convolutional neural network, for classifying quartz crystal from other rocks, achieving a 90% accuracy rate. The training and test images were capturing on a GoPro Hero 4 before being converted to images and processed within Nvidia DIGITS on a K80 based GPU instance.

1 Introduction

It is currently a time intensive process to identify and classify quartz crystals from other rocks in the mining industry. Separating quartz crystals from overburden by physical size characteristics is challenging because quartz can be any size. Also, quartz crystals are too fragile for the density separation processes used in gold ore processing.

Due to these limitations, this paper proposes an image recognition system for identifying quartz from overburden, then using this information for automated quartz separation by a movable physical barrier that would force overburden into a separate area.

In addition, Nvidia DIGITS is investigated for easy image classification tasks, including the quartz detector.

2 Background

The Nvidia DIGITS[1] interface was used to train the model, with AlexNet being used as the model format. DIGITS enables deep learning tasks to be easily performed, including managing data, training neural networks on multi-GPU systems, monitoring real time performance, and selecting the best performing model for deployment.

AlexNet [1] is a deep convolutional neural network (CNN) that was unveiled in 2012, and beat the next best model by 10.8% points in the 2012 ILSVRC[2]. The architecture contains eight layers, five being convolutional layers and the other three being fully connected layers. The output of the last fully connected layer is fed to a 3-way softmax which produces a distribution over the 3 class labels.

AlexNet includes a few notable features. The first of which is the use of Rectified Linear Units (ReLUs) instead of the equivalent tanh units. CNNs using ReLUs train multiple times faster than other units, while not requiring input normalization to prevent them from saturating (although AlexNet uses a

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[1] https://developer.nvidia.com/digits

[2] https://en.wikipedia.org/wiki/ImageNet#ImageNet_Challenge

custom local normalization scheme aids generalization). Dropout is also used in the first two fully connected layers to force the model to learn more robust features and prevent overfitting. This process makes each neuron have a 50% chance of turning off during the training of each image.

AlexNet was selected over GoogLeNet because it maintained acceptable accuracy while training and evaluating over three times as quick. For this robotic system, speed is more important than very high accuracy.

One important contraint with AlexNet is that the input imges must be 256 x 256 pixels, with 3 chanels (RGB).

2.1 DIGITS Example

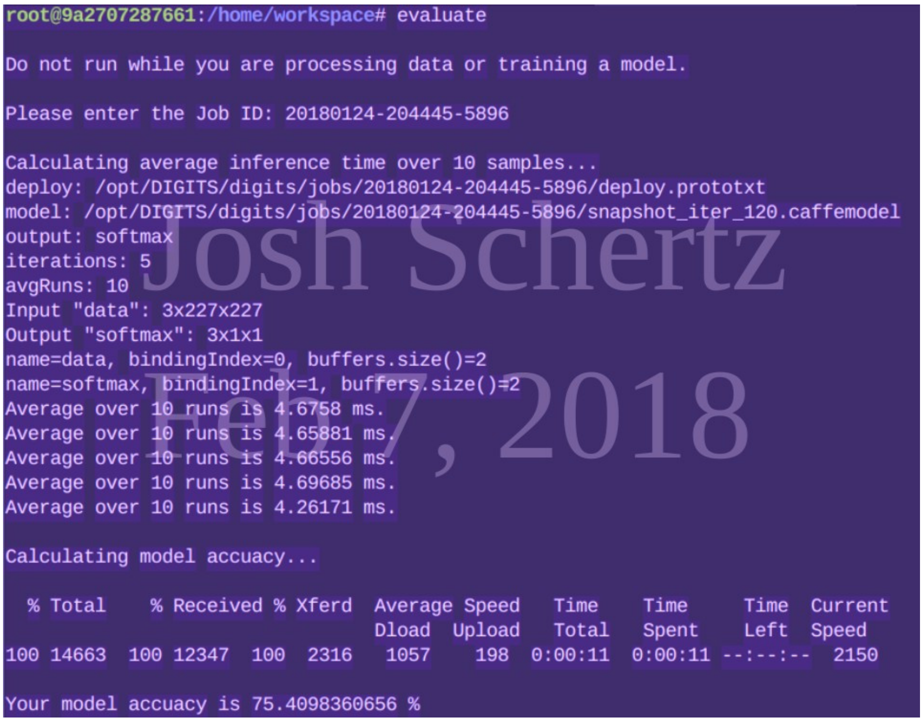
The DIGITS interface was evaluated by building a classification model identifying *bottles*, *candy boxes* and *nothing*. Figure 1 shows a few samples frames from this prelabeled data set.

Figure 1: sample frames from data set

Using AlexNet with only 2 training epochs and a learning rate of 0.01, the model finished training in 1 minute, 19 seconds using 7,750 images. Based on a random evaluation image pool, the model had an accuracy of 75.41% while spending less than 4.7 ms evaluating each image, as shown in Figure 2.

2.2 Quartz Detector

With the successful test of DIGITS, the custom Quartz Detector model could be trained. Three classes were provided, including *quartz*, *not_quartz* and *blank*, where each class' frames were separated into unique folders. For training, 2,498 quartz images, 2,614 non-quartz images and 317 blank images were provided.



```
root@9a2707287661:/home/workspace# evaluate

Do not run while you are processing data or training a model.

Please enter the Job ID: 20180124-204445-5896

Calculating average inference time over 10 samples...
deploy: /opt/DIGITS/digits/jobs/20180124-204445-5896/deploy.prototxt
model: /opt/DIGITS/digits/jobs/20180124-204445-5896/snapshot_iter_120.caffemodel
output: softmax
iterations: 5
avgRuns: 10
Input "data": 3x227x227
Output "softmax": 3x1x1
name=data, bindingIndex=0, buffers.size()=2
name=softmax, bindingIndex=1, buffers.size()=2
Average over 10 runs is 4.6758 ms.
Average over 10 runs is 4.65881 ms.
Average over 10 runs is 4.66556 ms.
Average over 10 runs is 4.69685 ms.
Average over 10 runs is 4.26171 ms.

Calculating model accuacy...

  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
100 14663  100 12347  100  2316   1057    198  0:00:11  0:00:11 --:--:--  2150

Your model accuacy is 75.4098360656 %
```


Figure 2: evaluation results showed the model had an accuracy of 75.41%

Model evaluation used completely unique rock samples to prevent bias. Figure 3 shows the rocks used for training and evaluating the model.

3 Data Acquisition

All images were derived from 240 fps WGVA video captured on a GoPro Hero 4. The video files were converted to 256 x 256 RGB PNG images where only the 24th video frame was saved (replicating a 10 fps video). The following ffmpeg terminal command was used to process the videos into images[3]:

```
$ for f in *.MP4;
> do ffmpeg -i "$f" -r 10 -s 256x256 ../../frames/quartz/"$f"_%04d.png;
> done
```

The videos were captured by holding the GoPro by hand, and circling the object when it was in the photo booth (pieces of printer paper assembled in a quarter semi hemisphere), as shown in figure 4.

I stored all images on OneDrive before downloading the zip file onto the instance used for DIGITS[4]. Once unzipped, the images within were loaded into a DIGITS database for use within the model.

[3]https://superuser.com/questions/135117/how-to-convert-video-to-images
[4]https://unix.stackexchange.com/a/378524

Figure 3: rocks used for training and evaluating model

4 Results

Figure 5 lists all the major variables for the classification model used, with notable items including a batch size of 10 and a learning rate of 0.01. Training the model with 10th epochs required 3 minutes and 15 seconds, achieving an accuracy of 98.26% and a loss of 0.048, as shown in figure 6

Evaluating the model performance on test images results in a lower accuracy of 90%, which is based on the number of test images correctly classified over the total number of test images.

4.1 Blank Classification

The blank images were always classified correctly, where most images had a confidence rating between 97% and 99%, as shown in figure 7. Figure 8 shows one test image that is correctly classified as a blank.

4.2 Quartz Classification

The images with quartz were classified mostly correct, although some frames were mis-classified as non-quartz images. Figure 9 shows that most of the frames are classified correctly with more than 99.5% confidence, however, if the angle and lighting are at certain levels, the model only has a confidence of about 50% in what they might be. For example, figure 10 and figure 11 both show correct classifications of a clear and yellow-ish quartz, respectively, while figure 12 shows an incorrect classification.

Figure 4: photo booth where a GoPro Hero 4 was used to capture the images

4.3 Non Quartz Classification

The images with non quartz rocks also were classified mostly correct, however, some rocks were incorrectly classified with uncertain confidence levels. Figure 13 shows a few test images of non quartz rocks. Many of the rock samples produced very high confidence levels when being classified, such as figure 14. Some rock samples confused the model when the angle and distance breached a certain frange. For instance, figure 15 shows a correctly classified sample with over 97% confidence, yet a slightly different angle of the same sample incorrectly classified the rock with a 69% confidence, as shown in figure 16.

5 Discussion

The Quartz Detection classification model has good accuracy and very quick processing speeds. Many of the incorrection image classifications can be attributed to lack of suffieicnt training material. This is mostly due to the non-static camera position and angle. If the camera were placed in a static location, with the samples being moved on a platform (or conveyor belt), the classification accuracy should increase further.

It is interesting to note that GoogLeNet had nearly perfect test accuracies, however, inference times were multiple times longer for both training and testing. As noted above, the inference time for this system is more important to ultimate accuracy, thus AlexNet is still a good choice.

The largest issue with the tested system is the lack of all potential rock types a mine could expect to process. However, the model should be able to achieve very high accuracies with a few thousand quartz and non quartz samples of all sizes expected, which is feasible.

6 Future Work

The Quartz Detector system explored in this paper seems to be a valid system for identifying quartz samples from over-burden. By increasing the training image size, the model should perform well in a production environment.

The next step to prove this system can be used in a production environment is to develop the hardware that will physically separate the quartz from the overburden. Some potential hardware expected include a conveyor system, a movable structure to perform the separation, and the computer and vision equipment to monitor and direct the system. The challenge with this will involve determining the timing for when and how quick to move the structure so the quartz is corrected separated from the non quartz samples.

References

[1] Alex Krizhevsky, Ilya Sutskever, and Geoffrey E Hinton. "ImageNet Classification with Deep Convolutional Neural Networks". In: *Advances in Neural Information Processing Systems 25*. Ed. by F. Pereira et al. Curran Associates, Inc., 2012, pp. 1097–1105. URL: `http://papers.nips.cc/paper/4824-imagenet-classification-with-deep-convolutional-neural-networks.pdf`.

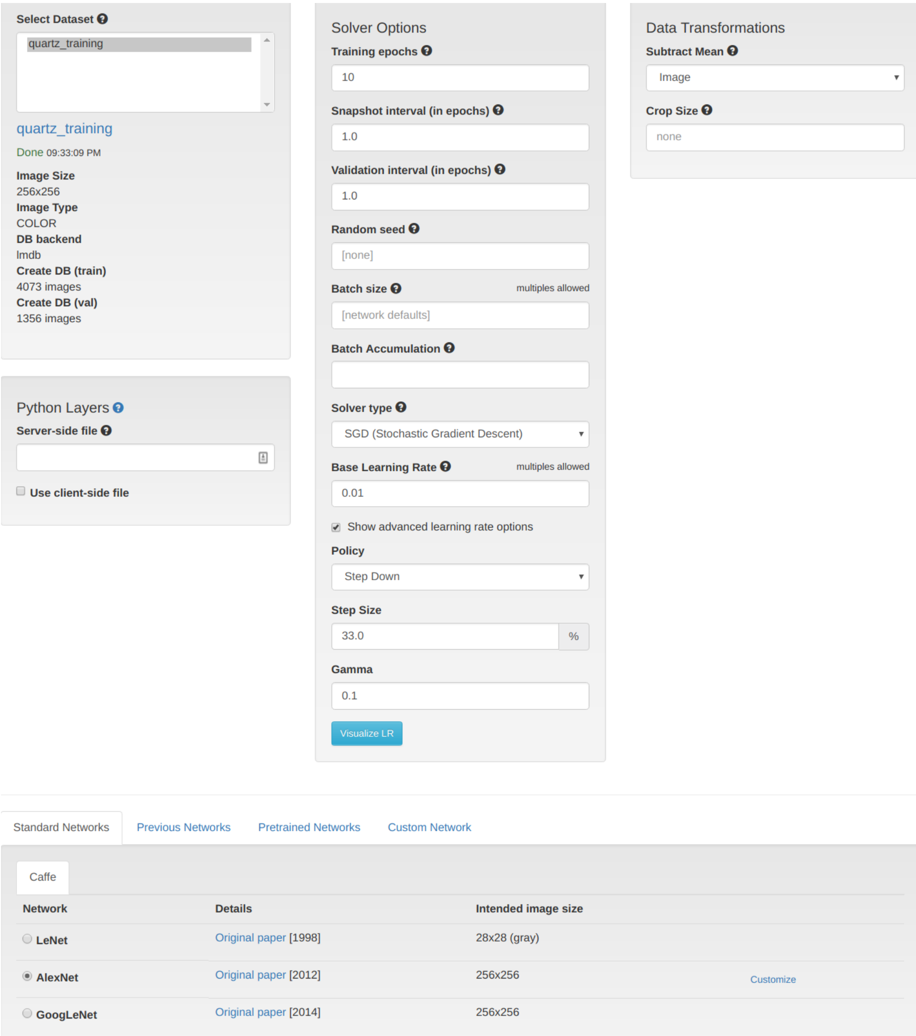


Figure 5: Nvidia DIGITS dashboard showing the model parameters used for Quartz Detector classifier

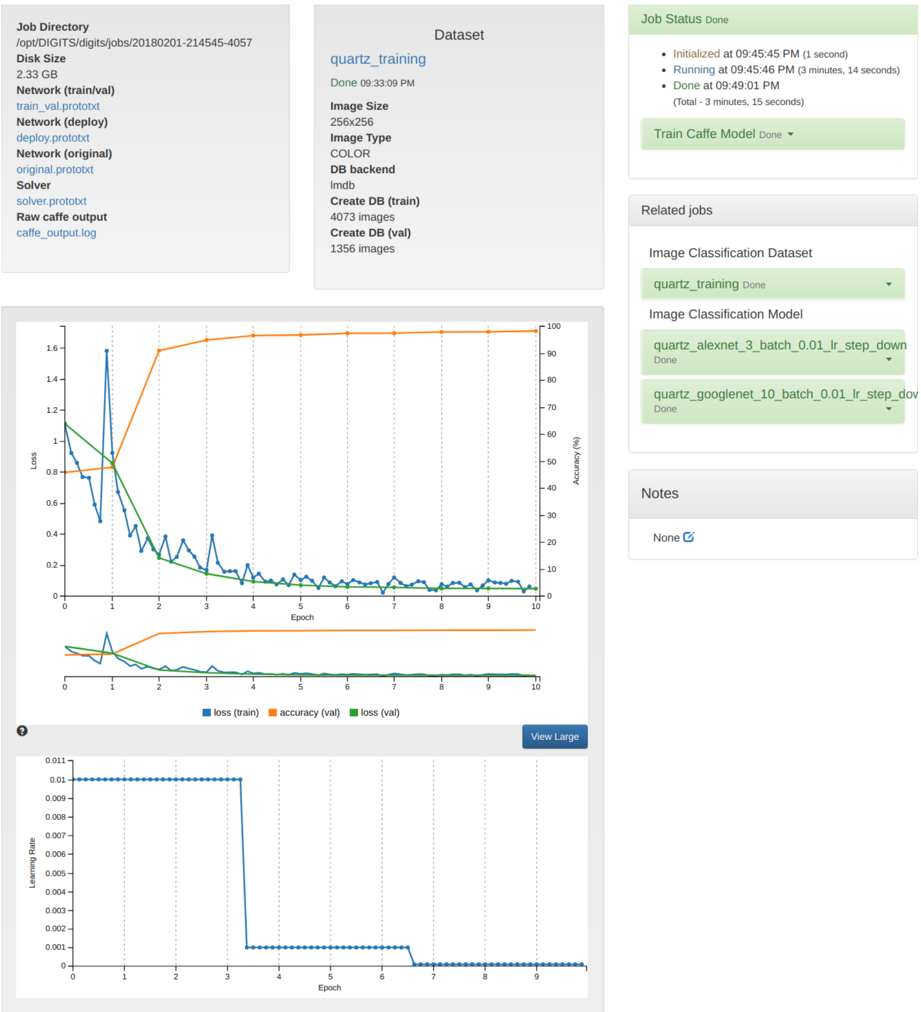


Figure 6: Nvidia DIGITS dashboard showing the trained performance of the Quartz Detector model

31	/data/quartz/test_frames/blank/GOPR0101.MP4_0190.png	blank	97.2%	quartz	1.96%	not quartz	0.84%
32	/data/quartz/test_frames/blank/GOPR0101.MP4_0191.png	blank	97.31%	quartz	1.9%	not quartz	0.79%
33	/data/quartz/test_frames/blank/GOPR0101.MP4_0192.png	blank	97.3%	quartz	1.88%	not quartz	0.82%
34	/data/quartz/test_frames/blank/GOPR0101.MP4_0193.png	blank	97.31%	quartz	1.88%	not quartz	0.81%
35	/data/quartz/test_frames/blank/GOPR0101.MP4_0194.png	blank	97.32%	quartz	1.92%	not quartz	0.76%
36	/data/quartz/test_frames/blank/GOPR0101.MP4_0195.png	blank	97.39%	quartz	1.89%	not quartz	0.72%
37	/data/quartz/test_frames/blank/GOPR0101.MP4_0196.png	blank	97.32%	quartz	2.0%	not quartz	0.68%
38	/data/quartz/test_frames/blank/GOPR0101.MP4_0197.png	blank	97.37%	quartz	2.0%	not quartz	0.63%
39	/data/quartz/test_frames/blank/GOPR0101.MP4_0198.png	blank	97.45%	quartz	1.97%	not quartz	0.58%
40	/data/quartz/test_frames/blank/GOPR0101.MP4_0199.png	blank	97.51%	quartz	1.91%	not quartz	0.58%
41	/data/quartz/test_frames/blank/GOPR0101.MP4_0200.png	blank	97.84%	quartz	1.48%	not quartz	0.68%
42	/data/quartz/test_frames/blank/GOPR0101.MP4_0201.png	blank	97.75%	quartz	1.34%	not quartz	0.91%
43	/data/quartz/test_frames/blank/GOPR0101.MP4_0202.png	blank	97.91%	quartz	1.09%	not quartz	1.01%
44	/data/quartz/test_frames/blank/GOPR0101.MP4_0203.png	blank	97.98%	quartz	1.05%	not quartz	0.97%
45	/data/quartz/test_frames/blank/GOPR0101.MP4_0204.png	blank	97.73%	quartz	1.21%	not quartz	1.06%
46	/data/quartz/test_frames/blank/GOPR0101.MP4_0205.png	blank	97.62%	quartz	1.22%	not quartz	1.16%
47	/data/quartz/test_frames/blank/GOPR0101.MP4_0206.png	blank	97.44%	not quartz	1.31%	quartz	1.24%
48	/data/quartz/test_frames/blank/GOPR0127.MP4_0001.png	blank	95.85%	quartz	3.72%	not quartz	0.43%
49	/data/quartz/test_frames/blank/GOPR0127.MP4_0002.png	blank	95.84%	quartz	3.73%	not quartz	0.43%
50	/data/quartz/test_frames/blank/GOPR0127.MP4_0003.png	blank	95.75%	quartz	3.83%	not quartz	0.42%
51	/data/quartz/test_frames/blank/GOPR0127.MP4_0004.png	blank	95.77%	quartz	3.76%	not quartz	0.47%
52	/data/quartz/test_frames/blank/GOPR0127.MP4_0005.png	blank	96.15%	quartz	3.36%	not quartz	0.49%
53	/data/quartz/test_frames/blank/GOPR0127.MP4_0006.png	blank	96.03%	quartz	3.45%	not quartz	0.52%
54	/data/quartz/test_frames/blank/GOPR0127.MP4_0007.png	blank	95.96%	quartz	3.41%	not quartz	0.63%
55	/data/quartz/test_frames/blank/GOPR0127.MP4_0008.png	blank	96.15%	quartz	3.23%	not quartz	0.63%
56	/data/quartz/test_frames/blank/GOPR0127.MP4_0009.png	blank	96.31%	quartz	3.03%	not quartz	0.66%
57	/data/quartz/test_frames/blank/GOPR0127.MP4_0010.png	blank	96.78%	quartz	2.65%	not quartz	0.57%
58	/data/quartz/test_frames/blank/GOPR0127.MP4_0011.png	blank	97.22%	quartz	2.08%	not quartz	0.7%
59	/data/quartz/test_frames/blank/GOPR0127.MP4_0012.png	blank	96.93%	quartz	2.35%	not quartz	0.73%
60	/data/quartz/test_frames/blank/GOPR0127.MP4_0013.png	blank	97.08%	quartz	2.19%	not quartz	0.73%
61	/data/quartz/test_frames/blank/GOPR0127.MP4_0014.png	blank	97.26%	quartz	1.95%	not quartz	0.8%
62	/data/quartz/test_frames/blank/GOPR0127.MP4_0015.png	blank	97.32%	quartz	1.96%	not quartz	0.72%
63	/data/quartz/test_frames/blank/GOPR0127.MP4_0016.png	blank	97.48%	quartz	1.86%	not quartz	0.65%
64	/data/quartz/test_frames/blank/GOPR0127.MP4_0017.png	blank	98.17%	quartz	1.3%	not quartz	0.53%
65	/data/quartz/test_frames/blank/GOPR0127.MP4_0018.png	blank	98.38%	quartz	1.16%	not quartz	0.47%
66	/data/quartz/test_frames/blank/GOPR0127.MP4_0019.png	blank	98.38%	quartz	1.14%	not quartz	0.49%
67	/data/quartz/test_frames/blank/GOPR0127.MP4_0020.png	blank	98.48%	quartz	1.02%	not quartz	0.5%
68	/data/quartz/test_frames/blank/GOPR0127.MP4_0021.png	blank	98.81%	quartz	0.63%	not quartz	0.56%
69	/data/quartz/test_frames/blank/GOPR0127.MP4_0022.png	blank	98.83%	quartz	0.61%	not quartz	0.56%

Figure 7: test blank images evaluated in model had very good classification results

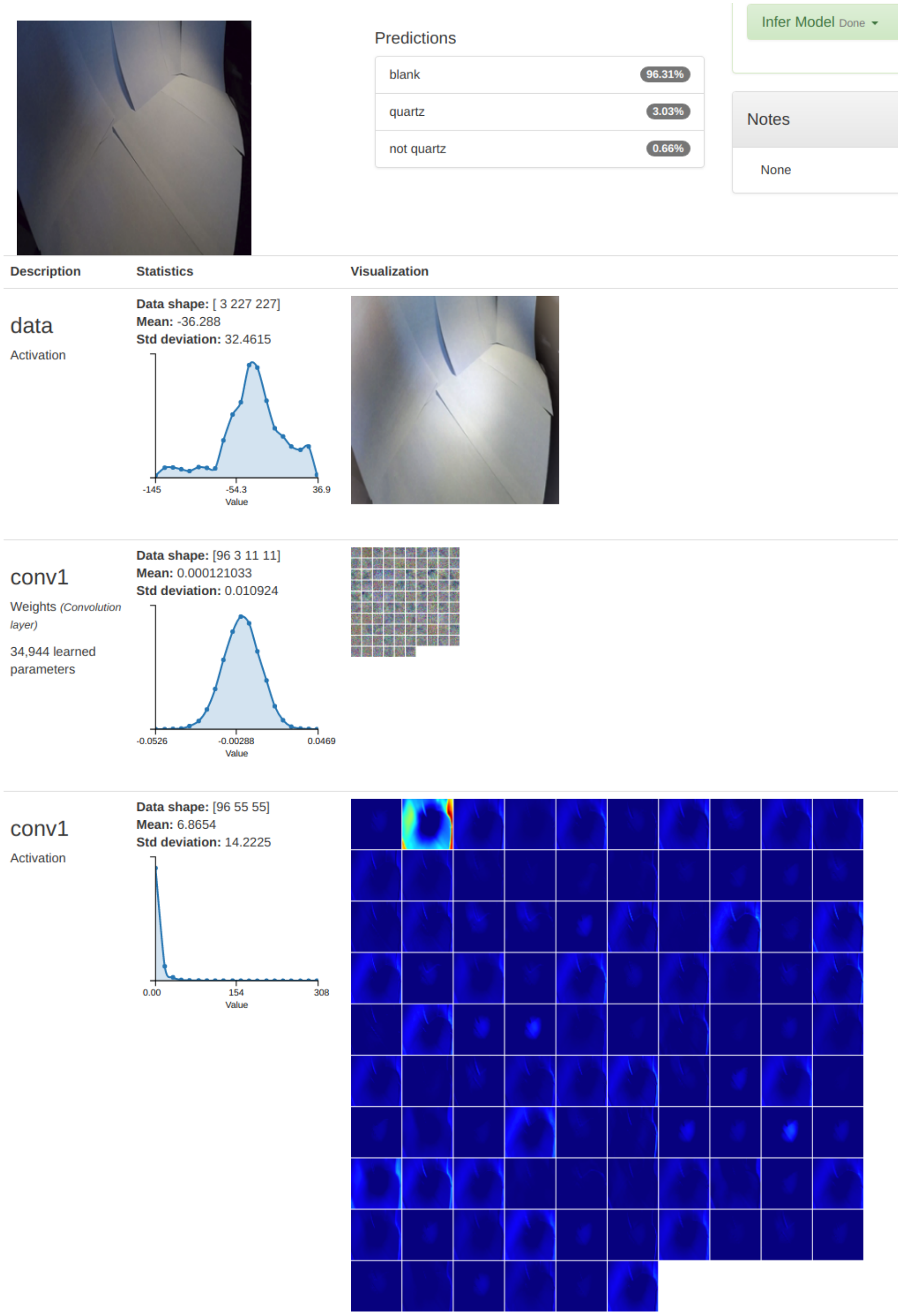


Figure 8: test image shows correct classification of blank

119	/data/quartz/test_frames/quartz/GOPR0089.MP4_0078.png	not quartz	49.79%	quartz	49.73%	blank	0.48%
120	/data/quartz/test_frames/quartz/GOPR0089.MP4_0079.png	quartz	55.67%	not quartz	43.96%	blank	0.37%
121	/data/quartz/test_frames/quartz/GOPR0089.MP4_0080.png	not quartz	56.29%	quartz	43.35%	blank	0.37%
122	/data/quartz/test_frames/quartz/GOPR0089.MP4_0081.png	not quartz	55.75%	quartz	43.87%	blank	0.38%
123	/data/quartz/test_frames/quartz/GOPR0089.MP4_0082.png	not quartz	55.62%	quartz	43.94%	blank	0.44%
124	/data/quartz/test_frames/quartz/GOPR0089.MP4_0083.png	quartz	67.69%	not quartz	31.91%	blank	0.4%
125	/data/quartz/test_frames/quartz/GOPR0089.MP4_0084.png	quartz	57.83%	not quartz	41.96%	blank	0.21%
126	/data/quartz/test_frames/quartz/GOPR0089.MP4_0085.png	quartz	57.19%	not quartz	42.66%	blank	0.15%
127	/data/quartz/test_frames/quartz/GOPR0089.MP4_0086.png	quartz	64.66%	not quartz	35.19%	blank	0.15%
128	/data/quartz/test_frames/quartz/GOPR0089.MP4_0087.png	quartz	60.91%	not quartz	38.98%	blank	0.11%
129	/data/quartz/test_frames/quartz/GOPR0089.MP4_0088.png	quartz	61.48%	not quartz	38.4%	blank	0.12%
130	/data/quartz/test_frames/quartz/GOPR0089.MP4_0089.png	quartz	56.4%	not quartz	43.47%	blank	0.12%
131	/data/quartz/test_frames/quartz/GOPR0089.MP4_0090.png	quartz	68.34%	not quartz	31.51%	blank	0.15%
132	/data/quartz/test_frames/quartz/GOPR0089.MP4_0091.png	quartz	86.53%	not quartz	13.17%	blank	0.3%
133	/data/quartz/test_frames/quartz/GOPR0089.MP4_0092.png	quartz	97.91%	not quartz	1.65%	blank	0.44%
134	/data/quartz/test_frames/quartz/GOPR0089.MP4_0093.png	quartz	98.23%	not quartz	1.43%	blank	0.35%
135	/data/quartz/test_frames/quartz/GOPR0089.MP4_0094.png	quartz	99.15%	blank	0.45%	not quartz	0.41%
136	/data/quartz/test_frames/quartz/GOPR0089.MP4_0095.png	quartz	98.88%	blank	0.64%	not quartz	0.48%
137	/data/quartz/test_frames/quartz/GOPR0089.MP4_0096.png	quartz	99.35%	blank	0.44%	not quartz	0.21%
138	/data/quartz/test_frames/quartz/GOPR0089.MP4_0097.png	quartz	99.6%	blank	0.29%	not quartz	0.11%
139	/data/quartz/test_frames/quartz/GOPR0089.MP4_0098.png	quartz	99.65%	blank	0.29%	not quartz	0.06%
140	/data/quartz/test_frames/quartz/GOPR0089.MP4_0099.png	quartz	99.68%	blank	0.26%	not quartz	0.05%
141	/data/quartz/test_frames/quartz/GOPR0089.MP4_0100.png	quartz	99.71%	blank	0.25%	not quartz	0.04%
142	/data/quartz/test_frames/quartz/GOPR0089.MP4_0101.png	quartz	99.67%	blank	0.3%	not quartz	0.03%
143	/data/quartz/test_frames/quartz/GOPR0089.MP4_0102.png	quartz	99.65%	blank	0.33%	not quartz	0.03%
144	/data/quartz/test_frames/quartz/GOPR0089.MP4_0103.png	quartz	99.62%	blank	0.36%	not quartz	0.03%
145	/data/quartz/test_frames/quartz/GOPR0089.MP4_0104.png	quartz	99.67%	blank	0.31%	not quartz	0.02%
146	/data/quartz/test_frames/quartz/GOPR0089.MP4_0105.png	quartz	99.64%	blank	0.35%	not quartz	0.01%
147	/data/quartz/test_frames/quartz/GOPR0099.MP4_0001.png	quartz	99.66%	not quartz	0.31%	blank	0.03%
148	/data/quartz/test_frames/quartz/GOPR0099.MP4_0002.png	quartz	99.66%	not quartz	0.31%	blank	0.03%
149	/data/quartz/test_frames/quartz/GOPR0099.MP4_0003.png	quartz	99.66%	not quartz	0.31%	blank	0.03%
150	/data/quartz/test_frames/quartz/GOPR0099.MP4_0004.png	quartz	99.68%	not quartz	0.29%	blank	0.03%
151	/data/quartz/test_frames/quartz/GOPR0099.MP4_0005.png	quartz	99.7%	not quartz	0.26%	blank	0.03%
152	/data/quartz/test_frames/quartz/GOPR0099.MP4_0006.png	quartz	99.72%	not quartz	0.25%	blank	0.03%
153	/data/quartz/test_frames/quartz/GOPR0099.MP4_0007.png	quartz	99.77%	not quartz	0.2%	blank	0.03%
154	/data/quartz/test_frames/quartz/GOPR0099.MP4_0008.png	quartz	99.78%	not quartz	0.2%	blank	0.03%
155	/data/quartz/test_frames/quartz/GOPR0099.MP4_0009.png	quartz	99.76%	not quartz	0.22%	blank	0.03%
156	/data/quartz/test_frames/quartz/GOPR0099.MP4_0010.png	quartz	99.72%	not quartz	0.25%	blank	0.03%
157	/data/quartz/test_frames/quartz/GOPR0099.MP4_0011.png	quartz	99.71%	not quartz	0.26%	blank	0.03%
158	/data/quartz/test_frames/quartz/GOPR0099.MP4_0012.png	quartz	99.69%	not quartz	0.28%	blank	0.03%
159	/data/quartz/test_frames/quartz/GOPR0099.MP4_0013.png	quartz	99.71%	not quartz	0.26%	blank	0.03%
160	/data/quartz/test_frames/quartz/GOPR0099.MP4_0014.png	quartz	99.77%	not quartz	0.2%	blank	0.03%

Figure 9: test frames showing the confidence in classifying quartz images

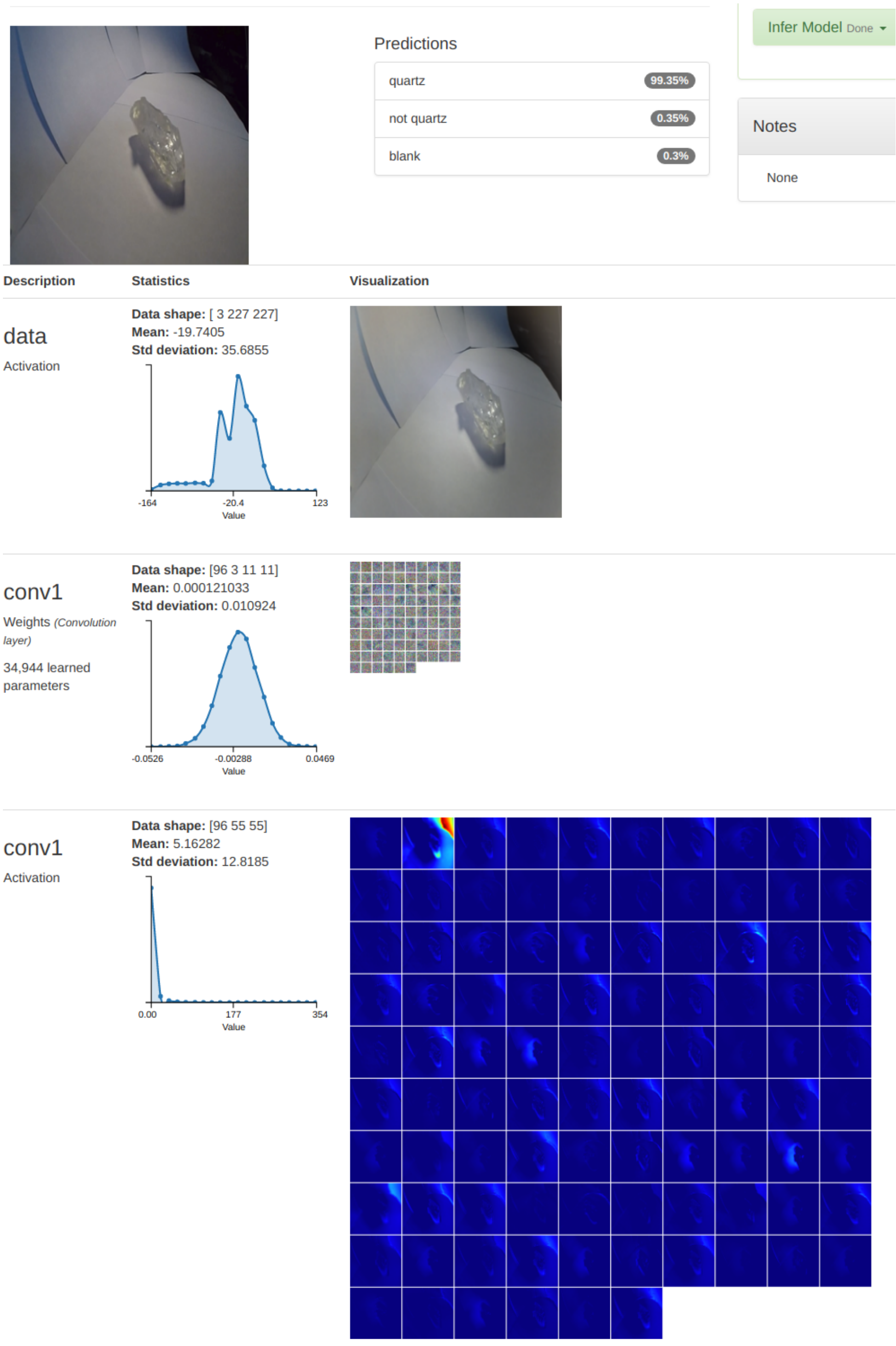


Figure 10: test image shows correct classification of a clear quartz

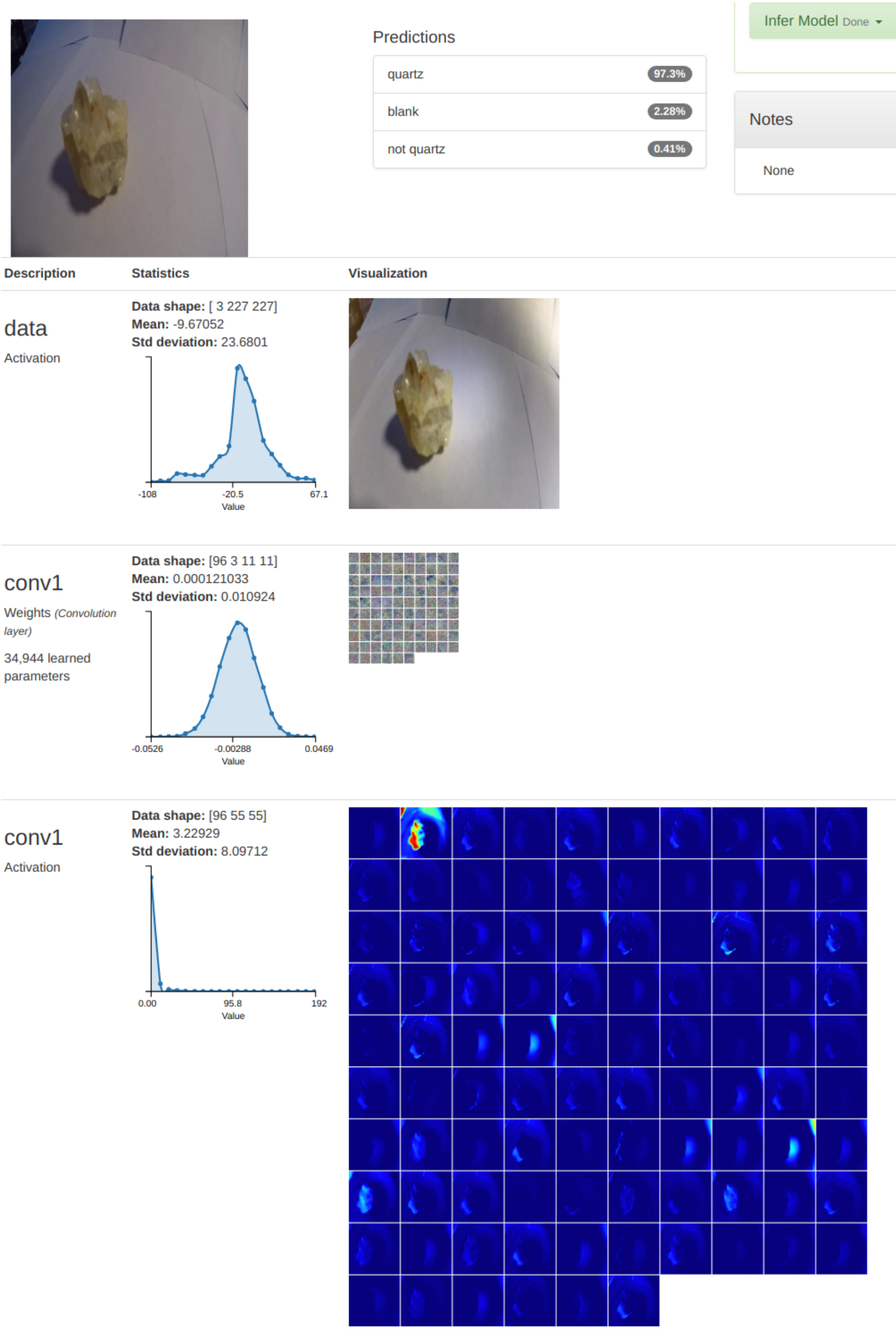


Figure 11: test image shows correct classification of a yellow-ish quartz

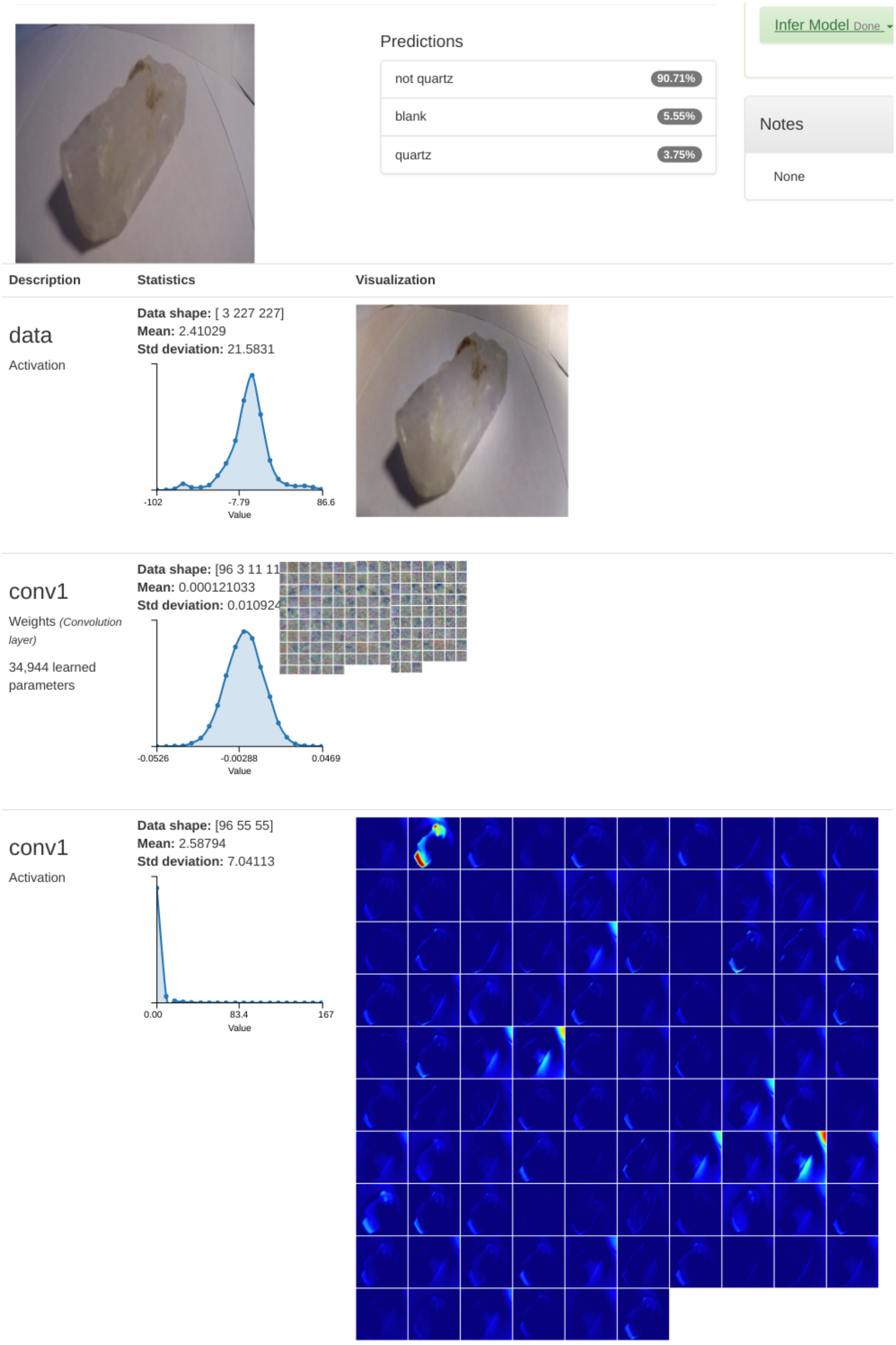


Figure 12: test image shows wrong classification of a clear quartz

87	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0087.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
88	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0088.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
89	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0089.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
90	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0090.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
91	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0091.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
92	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0092.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
93	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0093.png	not quartz	100.0%	quartz	0.0%	blank	0.0%
94	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0094.png	not quartz	99.99%	quartz	0.01%	blank	0.0%
95	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0095.png	not quartz	99.99%	quartz	0.01%	blank	0.0%
96	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0096.png	not quartz	99.99%	quartz	0.01%	blank	0.0%
97	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0097.png	not quartz	99.99%	quartz	0.01%	blank	0.0%
98	/data/quartz/test_frames/not_quartz/GOPR0103.MP4_0098.png	not quartz	99.99%	quartz	0.01%	blank	0.0%
99	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0001.png	not quartz	97.09%	quartz	2.91%	blank	0.0%
100	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0002.png	not quartz	97.0%	quartz	3.0%	blank	0.0%
101	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0003.png	not quartz	97.4%	quartz	2.6%	blank	0.0%
102	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0004.png	not quartz	98.18%	quartz	1.82%	blank	0.0%
103	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0005.png	not quartz	99.12%	quartz	0.88%	blank	0.0%
104	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0006.png	not quartz	99.33%	quartz	0.67%	blank	0.0%
105	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0007.png	not quartz	99.5%	quartz	0.5%	blank	0.0%
106	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0008.png	not quartz	99.62%	quartz	0.37%	blank	0.0%
107	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0009.png	not quartz	99.75%	quartz	0.25%	blank	0.0%
108	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0010.png	not quartz	99.62%	quartz	0.38%	blank	0.0%
109	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0011.png	not quartz	98.79%	quartz	1.21%	blank	0.0%
110	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0012.png	not quartz	97.71%	quartz	2.29%	blank	0.0%
111	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0013.png	not quartz	97.62%	quartz	2.38%	blank	0.0%
112	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0014.png	not quartz	96.16%	quartz	3.84%	blank	0.0%
113	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0015.png	not quartz	92.09%	quartz	7.91%	blank	0.0%
114	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0016.png	not quartz	79.24%	quartz	20.76%	blank	0.0%
115	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0017.png	not quartz	67.26%	quartz	32.73%	blank	0.0%
116	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0018.png	not quartz	52.08%	quartz	47.91%	blank	0.0%
117	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0019.png	quartz	53.2%	not quartz	46.8%	blank	0.0%
118	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0020.png	not quartz	54.62%	quartz	45.38%	blank	0.0%
119	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0021.png	not quartz	59.52%	quartz	40.48%	blank	0.0%
120	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0022.png	not quartz	64.05%	quartz	35.94%	blank	0.0%
121	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0023.png	not quartz	59.65%	quartz	40.35%	blank	0.0%
122	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0024.png	quartz	54.84%	not quartz	45.15%	blank	0.01%
123	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0025.png	quartz	61.91%	not quartz	38.09%	blank	0.01%
124	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0026.png	quartz	53.14%	not quartz	46.85%	blank	0.01%
125	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0027.png	quartz	59.78%	not quartz	40.22%	blank	0.01%
126	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0028.png	quartz	69.2%	not quartz	30.78%	blank	0.01%
127	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0029.png	quartz	55.23%	not quartz	44.76%	blank	0.01%
128	/data/quartz/test_frames/not_quartz/GOPR0120.MP4_0030.png	not quartz	59.25%	quartz	40.74%	blank	0.01%

Figure 13: test frames showing the confidence in classifying non quartz images

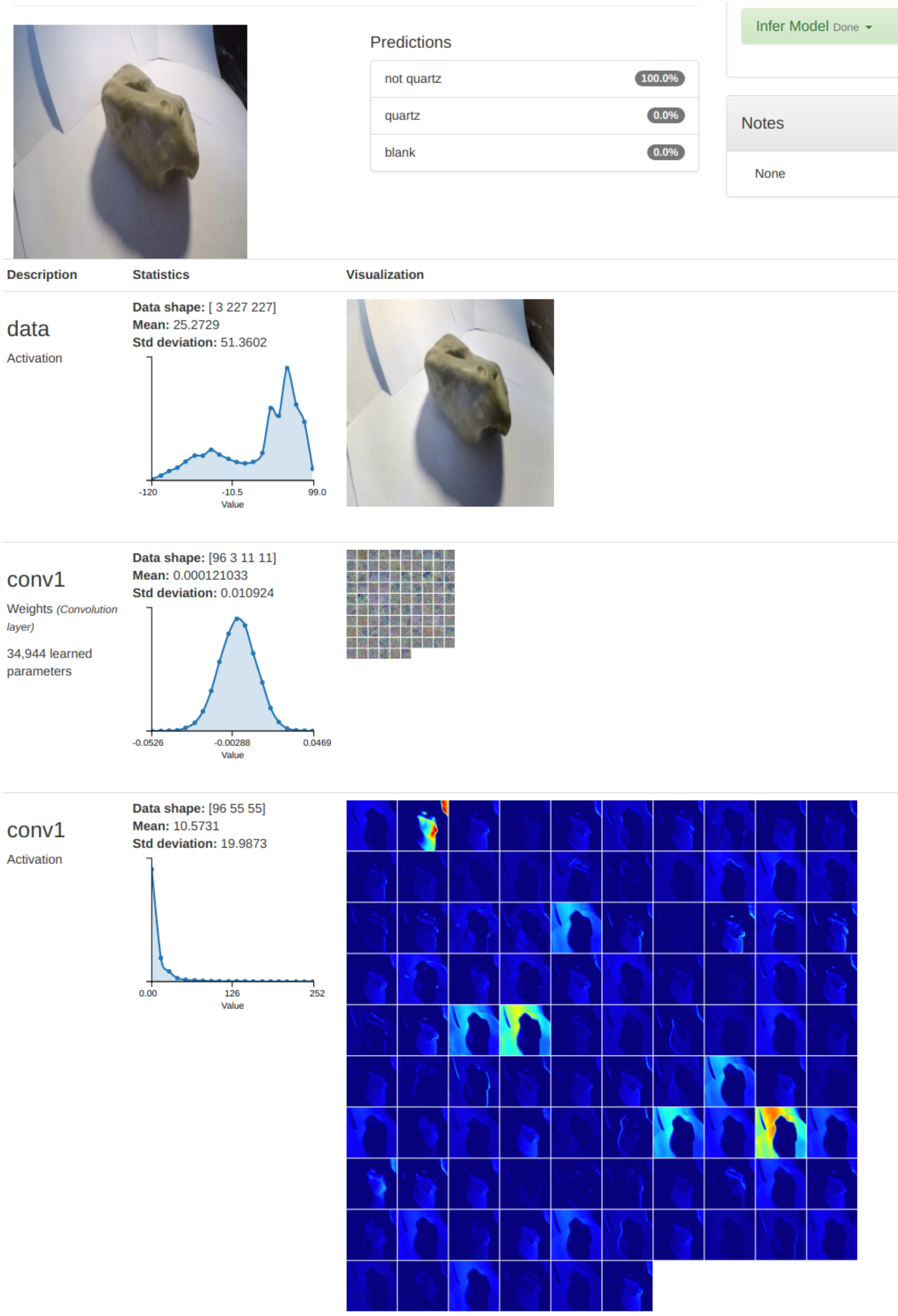


Figure 14: test image shows correct classification of a round non quartz sample

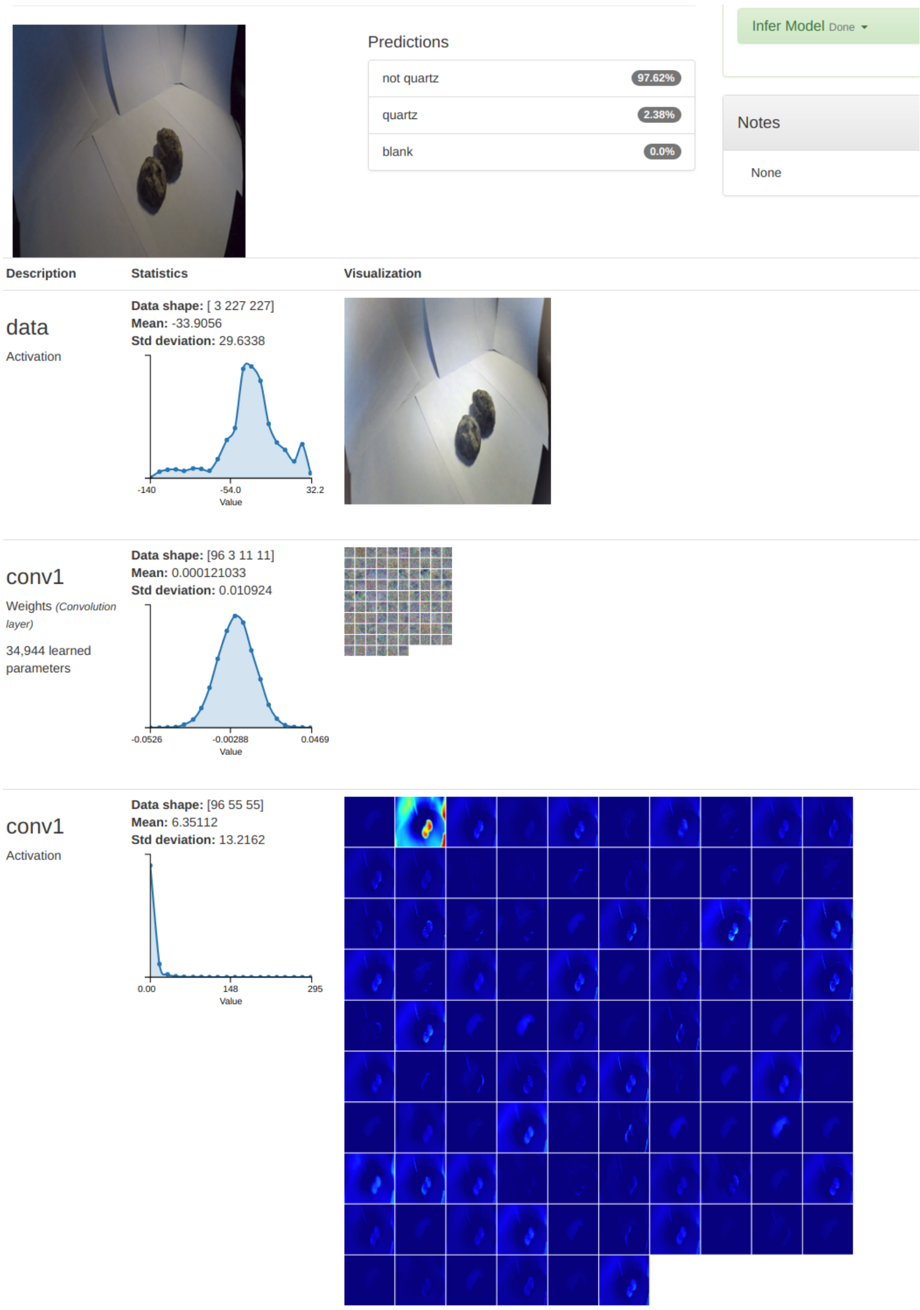


Figure 15: test image shows correct classification of two small non quartz samples

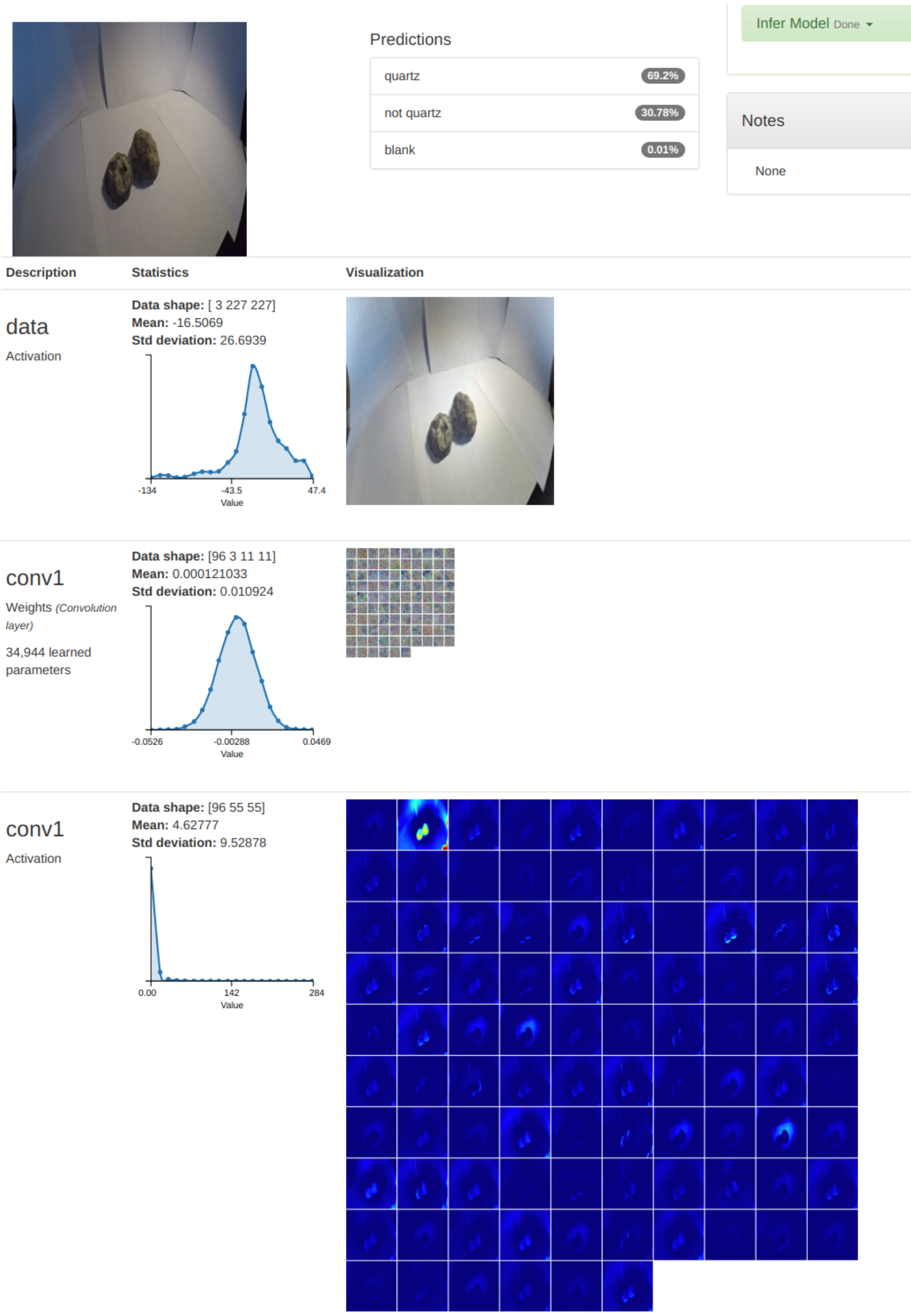


Figure 16: test image shows wrong classification of two small non quartz samples