

Assignment#4

Modulation Classification

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load data

```

1 # Load the dataset
2 file = open("../content/drive/MyDrive/DM_4/Data/RML2016.10b.dat",'rb')
3 Xd = cPickle.load(file, encoding = 'latin1')
4 snrs,mods = map(lambda j: sorted(list(set(map(lambda x: x[j], Xd.keys())))), [1,0])
5 X = []
6 lbl = []
7 for mod in mods:
8     for snr in snrs:
9         X.append(Xd[(mod,snr)])
10        for i in range(Xd[(mod,snr)].shape[0]): lbl.append((mod,snr))
11 X = np.vstack(X)
12 file.close()
13

# num exist classes
classes = mods

```

['BPSK', 'AM-DSB', 'BPSK', 'CPFSK', 'GFSK', 'PAM4', 'QAM16', 'QAM64', 'QPSK', 'WBFM'] 10

Create Features Space

```

1 features = {}
2
3 #Raw Time Feature
4 features['raw'] = X[:,0], X[:,1]
5
6 #First derivative in time
7 features['derivative'] = normalize(np.gradient(X[:,0], axis = 1)), normalize(np.gradient(X[:,1], axis = 1))
8
9 #Integral in time
10 features['integral'] = normalize(np.cumsum(X[:,0], axis = 1)), normalize(np.cumsum(X[:,1], axis = 1))
11
12 #combinations of 1,2 and 3
13 def extract_features(*arguments):
14     desired = ()
15     for arg in arguments:
16         desired += features[arg]
17     return np.stack(desired, axis = 1)

```

Split data into training/validation and testing

```

data shape (1200000, 2, 128)
labels shape (1200000, 2)
labels [[ '8PSK' '-20']
 ['8PSK' '-20']

...
['WBFM' '18']
['WBFM' '18']]
train examples 840000
test examples 360000
Y_train shape(840000, 10)

```

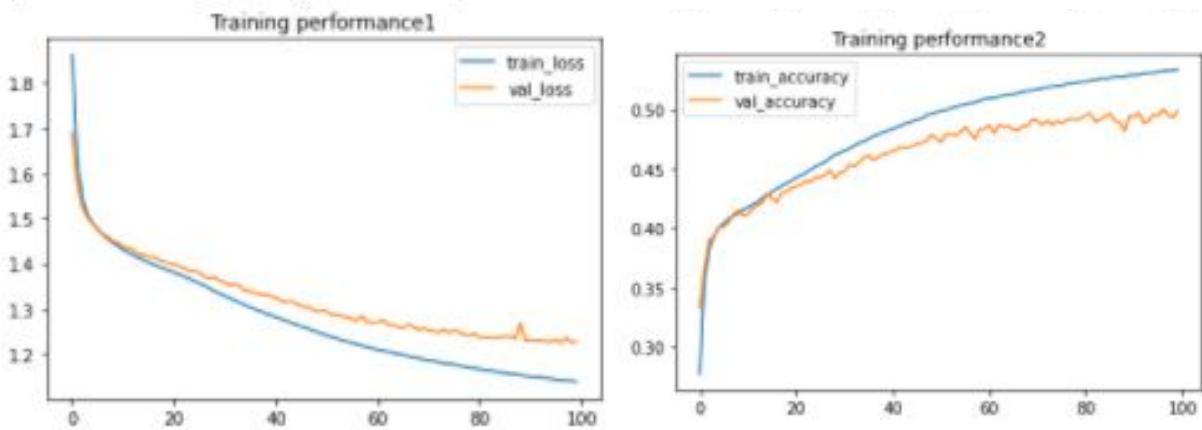
Model fully connected dense layer

Layer (type)	Output Shape	Param #
dense_4 (Dense)	(None, 2, 512)	66848
dense_5 (Dense)	(None, 2, 256)	131328
flatten_2 (Flatten)	(None, 512)	0
dense_6 (Dense)	(None, 10)	5130

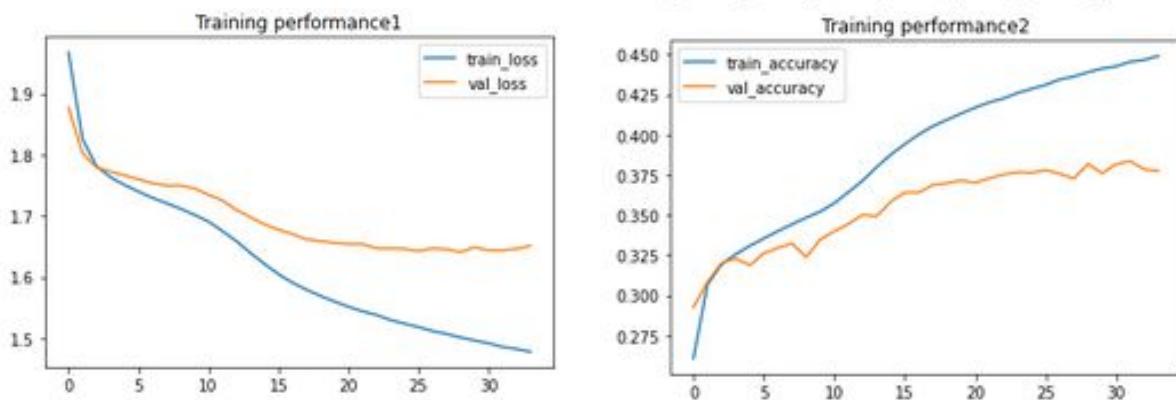
Total params: 282,506
 Trainable params: 282,506
 Non-trainable params: 0

Training

1-with raw feature

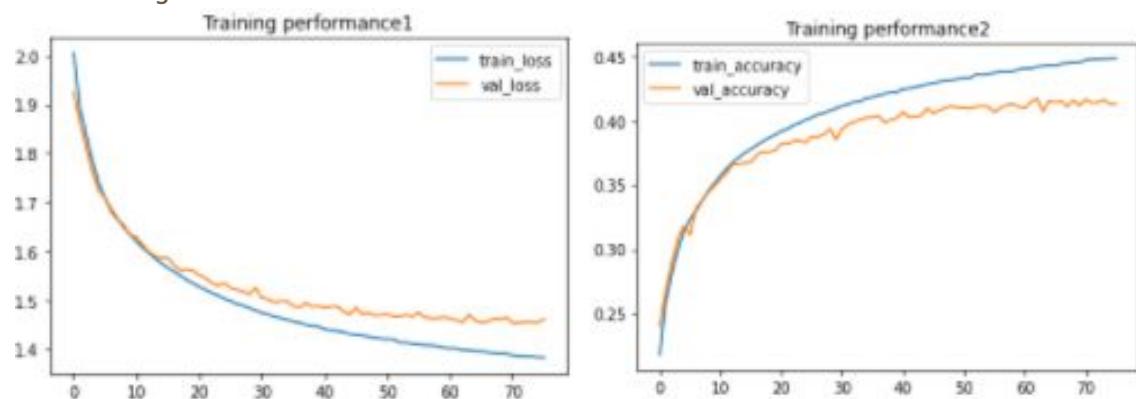


2-with derivative feature





3-with Integral feature



Testing

1-with raw feature

Loss accuracy
[1.2350635528564453, 0.4950805604457855]

2-with derivative feature

Loss accuracy
[1.6407184600830078, 0.3845277726650238]

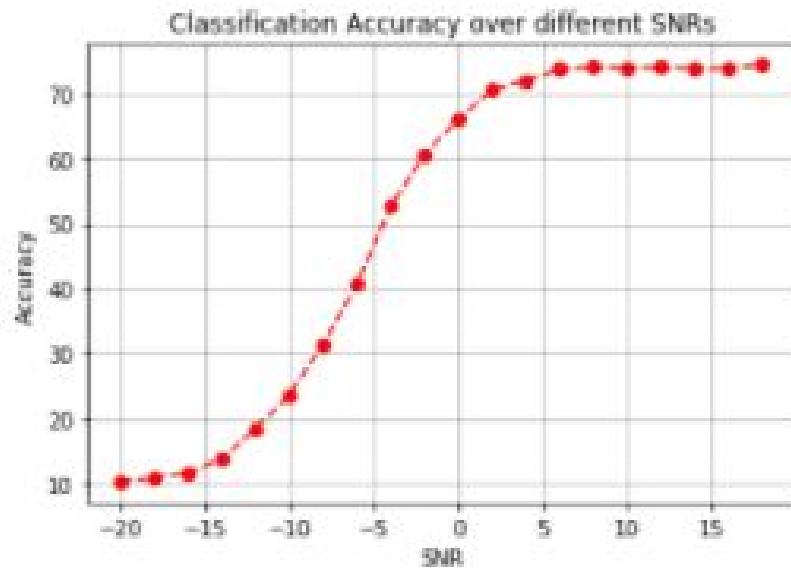
3-with Integral feature

Loss [1.4496387243270874], accuracy 0.41671112179756165]

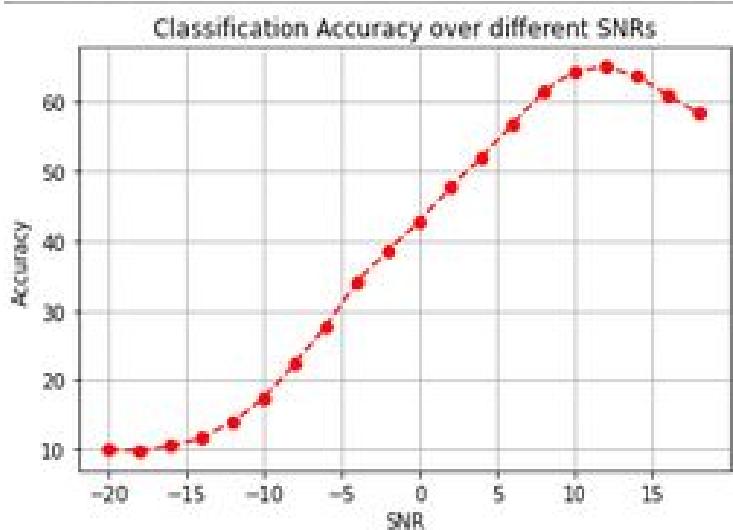
accuracy against the SNR

1-with

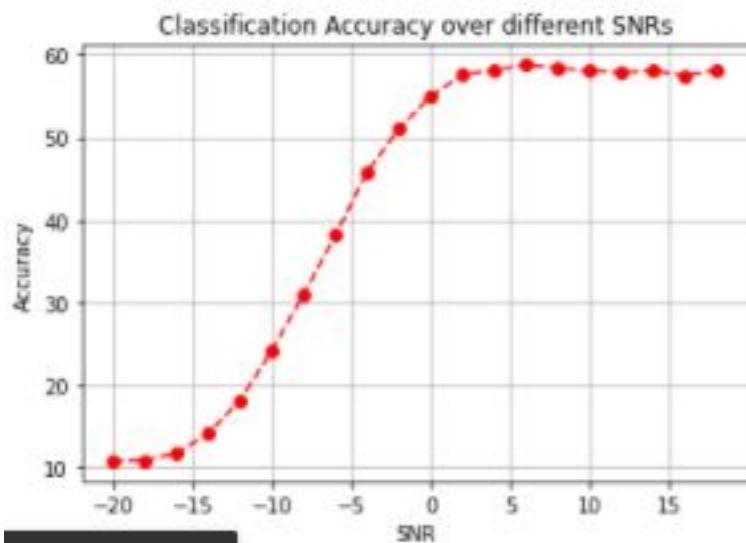
1-with raw feature



2-with derivative feature



3-with Integral feature



average overall accuracy

1-with raw feature

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.46	11.08	11.83	13.98	18.56	23.69	31.6	40.67	52.67	60.64	66.04	70.49	72.01	73.7	74.04	73.91	73.99	73.88	73.79	74.38

2-with derivative feature

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.0	9.83	10.54	11.7	14.07	17.48	22.44	27.78	34.19	38.64	42.87	47.67	52.05	56.77	61.49	64.37	65.01	63.67	60.78	58.3

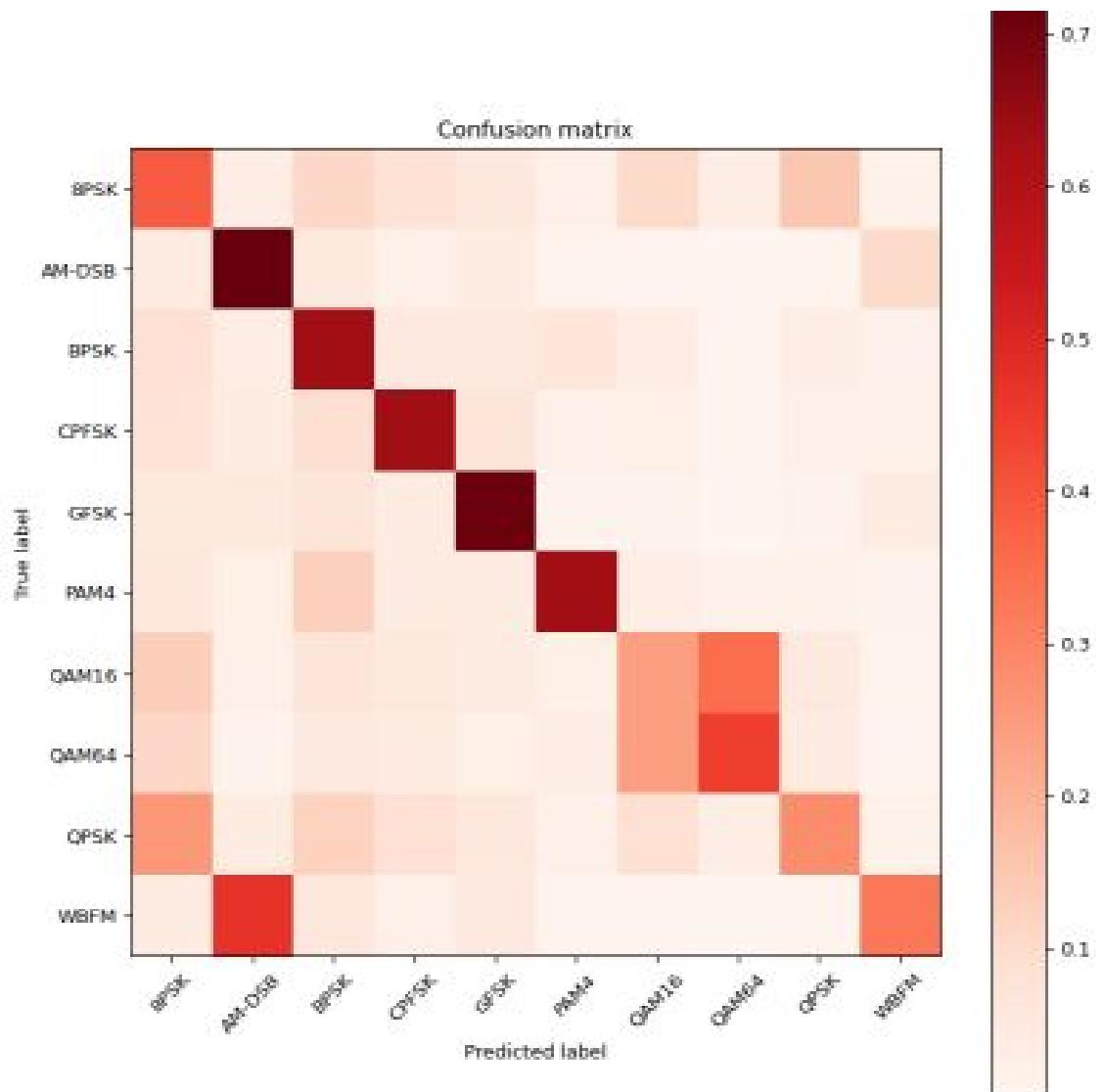


3-with Integral feature

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.85	10.93	11.79	14.13	18.17	24.19	31.01	38.17	45.81	51.08	54.98	57.63	58.14	58.82	58.41	58.1	57.86	58.09	57.49	58.17

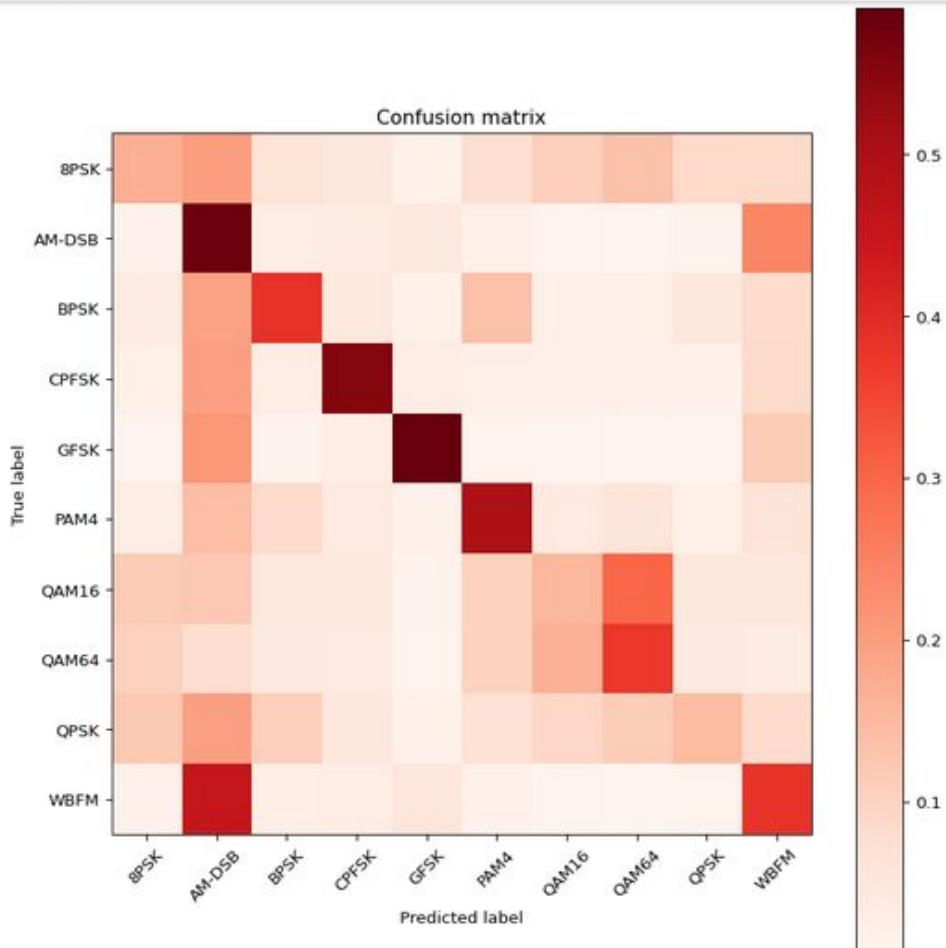
confusion matrices

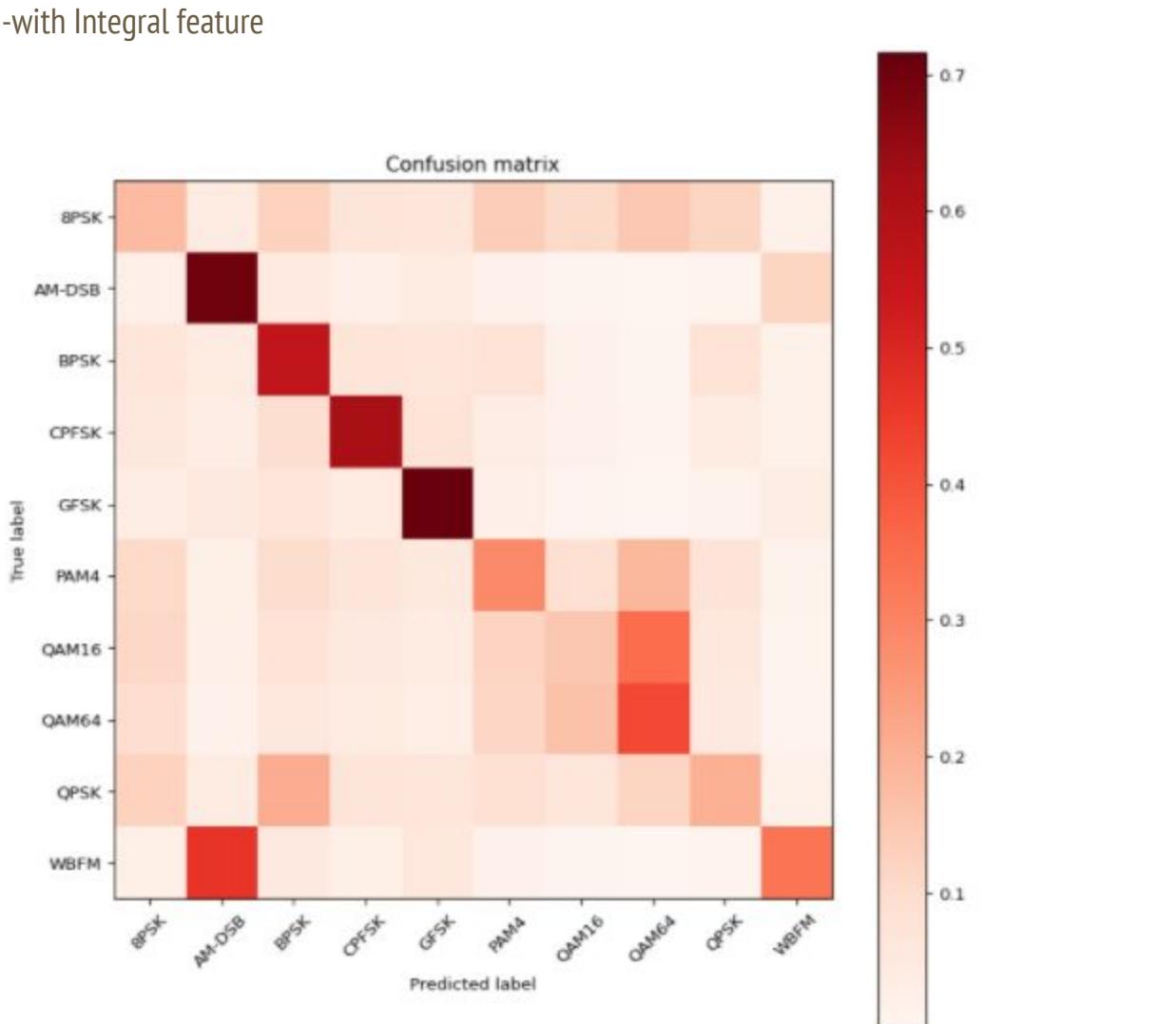
1-with raw feature





2-with derivative feature



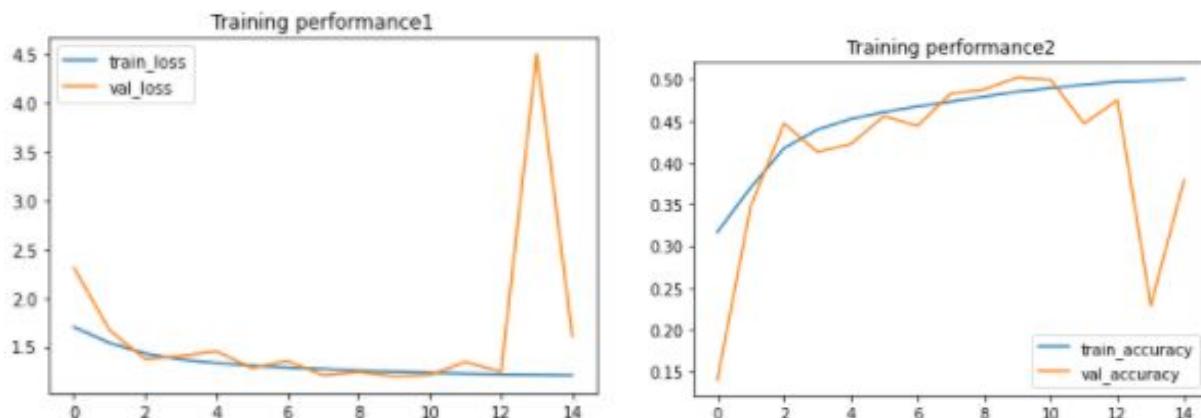


CNN

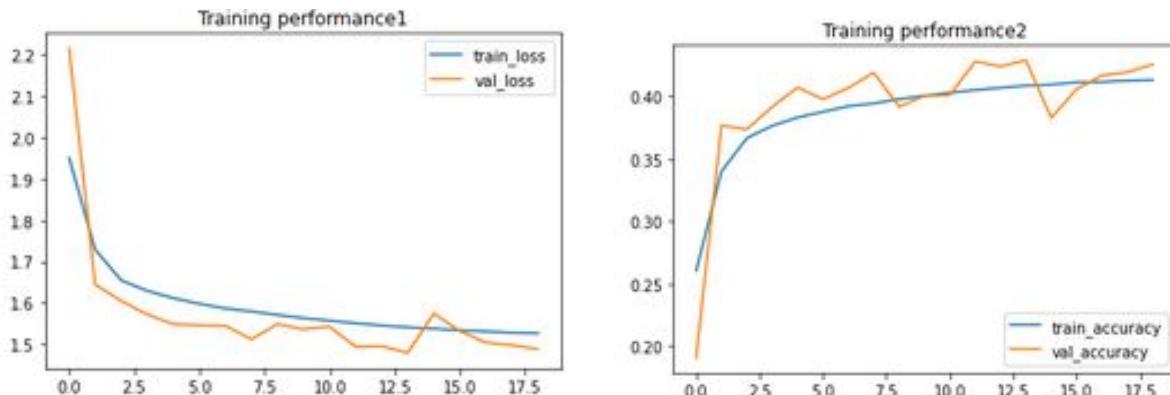
Layer (type)	Output Shape	Param #
<hr/>		
reshape_1 (Reshape)	(None, 128, 2, 1)	0
conv2d_2 (Conv2D)	(None, 128, 2, 64)	256
batch_normalization_1 (Batch Normalization)	(None, 128, 2, 64)	256
max_pooling2d_1 (MaxPooling2D)	(None, 64, 1, 64)	0
conv2d_3 (Conv2D)	(None, 64, 1, 16)	6160
flatten_1 (Flatten)	(None, 1024)	0
dropout_1 (Dropout)	(None, 1024)	0
dense_2 (Dense)	(None, 128)	131200
dense_3 (Dense)	(None, 10)	1290
<hr/>		
Total params:	139,162	
Trainable params:	139,034	
Non-trainable params:	128	

Training

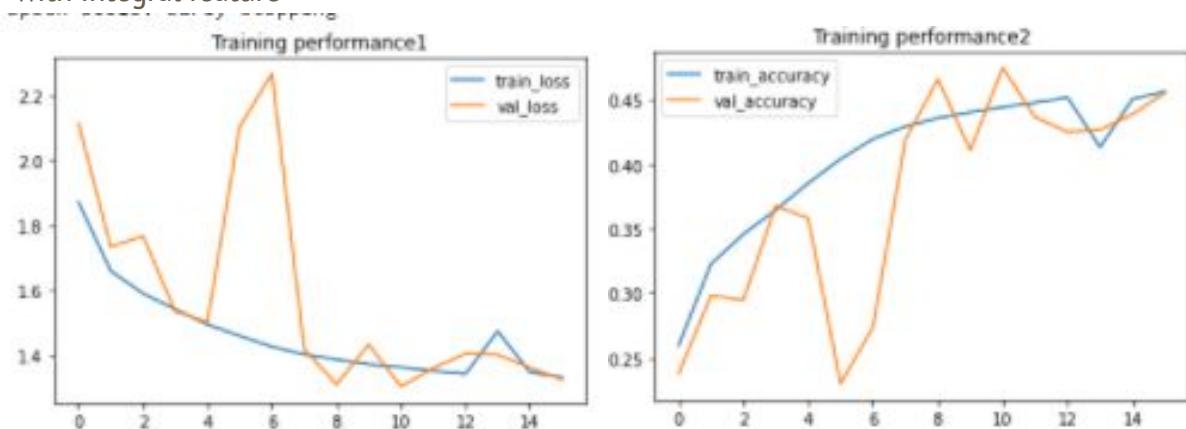
1-with raw feature



2-with derivative feature



3-with Integral feature



Testing

1-with raw feature

Loss [1.1945147514343262, 0.5029416680335999]
 accuracy

2-with derivative feature

Loss [1.4803590774536133, 0.4301472306251526]
 accuracy

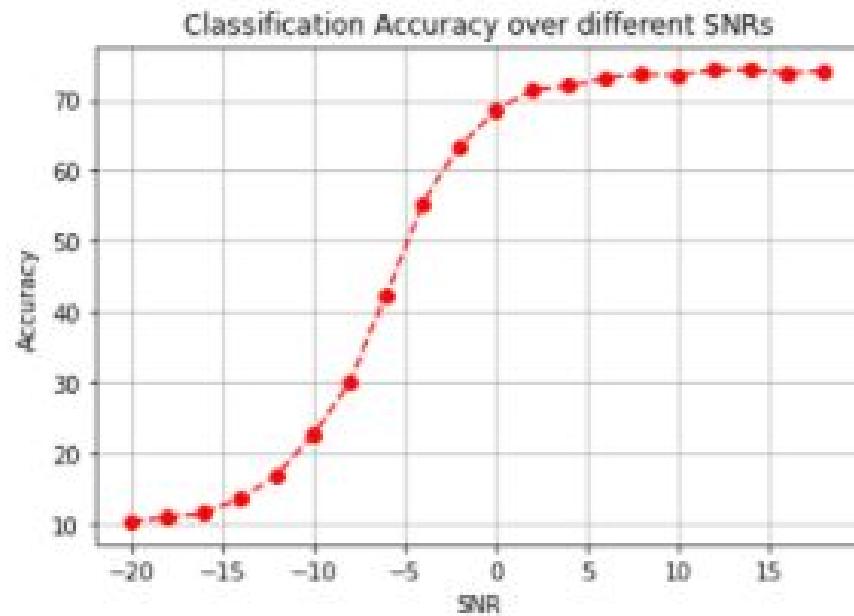
3-with Integral feature

Loss [1.3041434288024902, 0.4751444458961487]
 accuracy

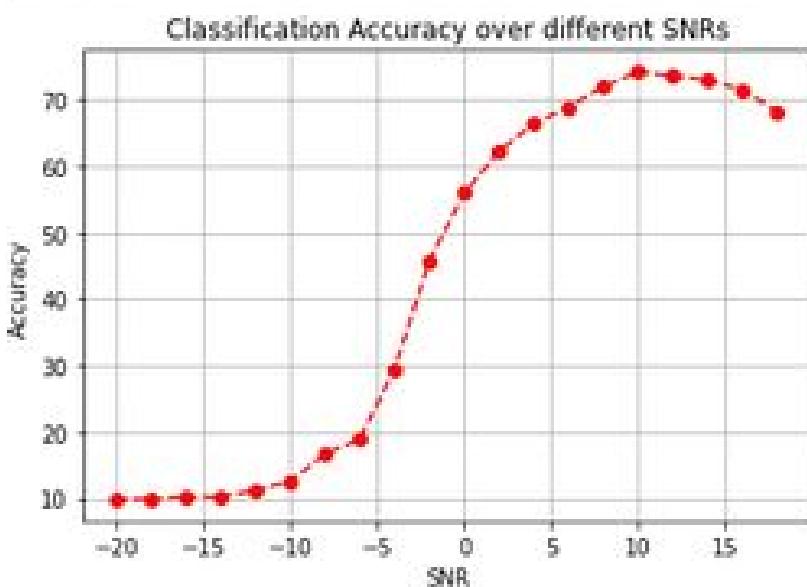


accuracy against the SNR

1-with raw feature

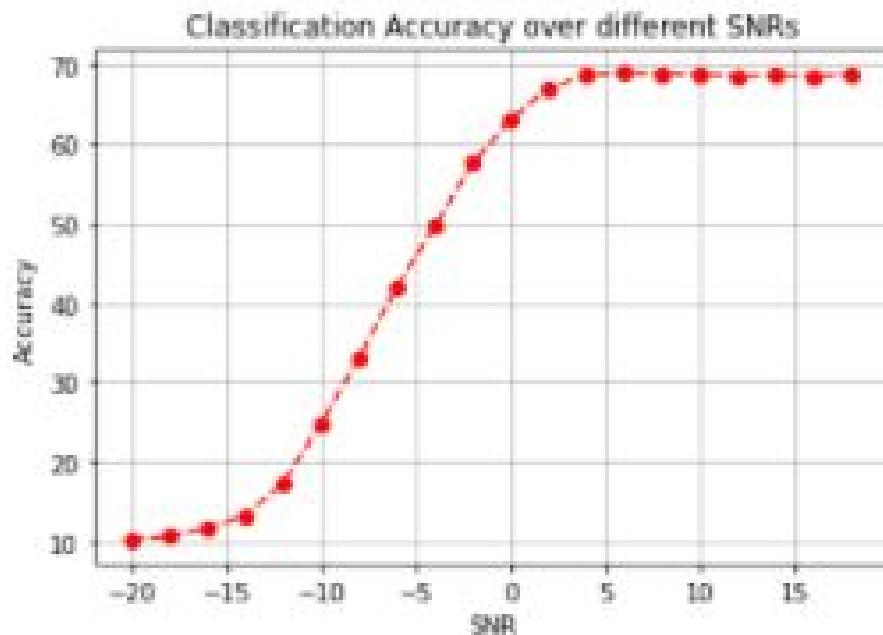


2-with derivative feature





3-with Integral feature



average overall accuracy

1-with raw feature

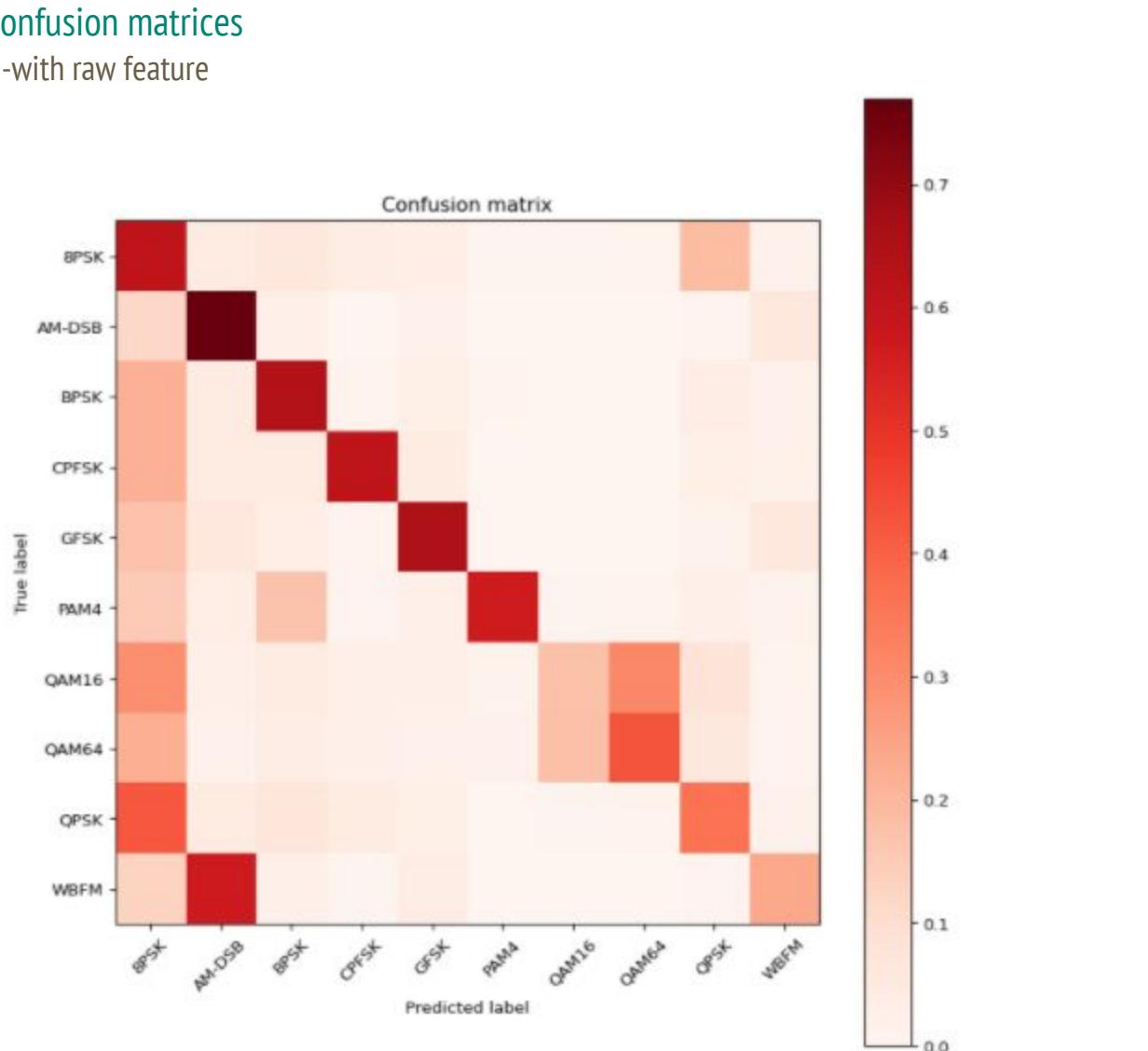
	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.43	11.04	11.58	13.54	16.99	22.67	30.08	42.52	55.37	63.53	68.48	71.45	71.95	73.1	73.66	73.54	74.28	74.29	73.79	74.17

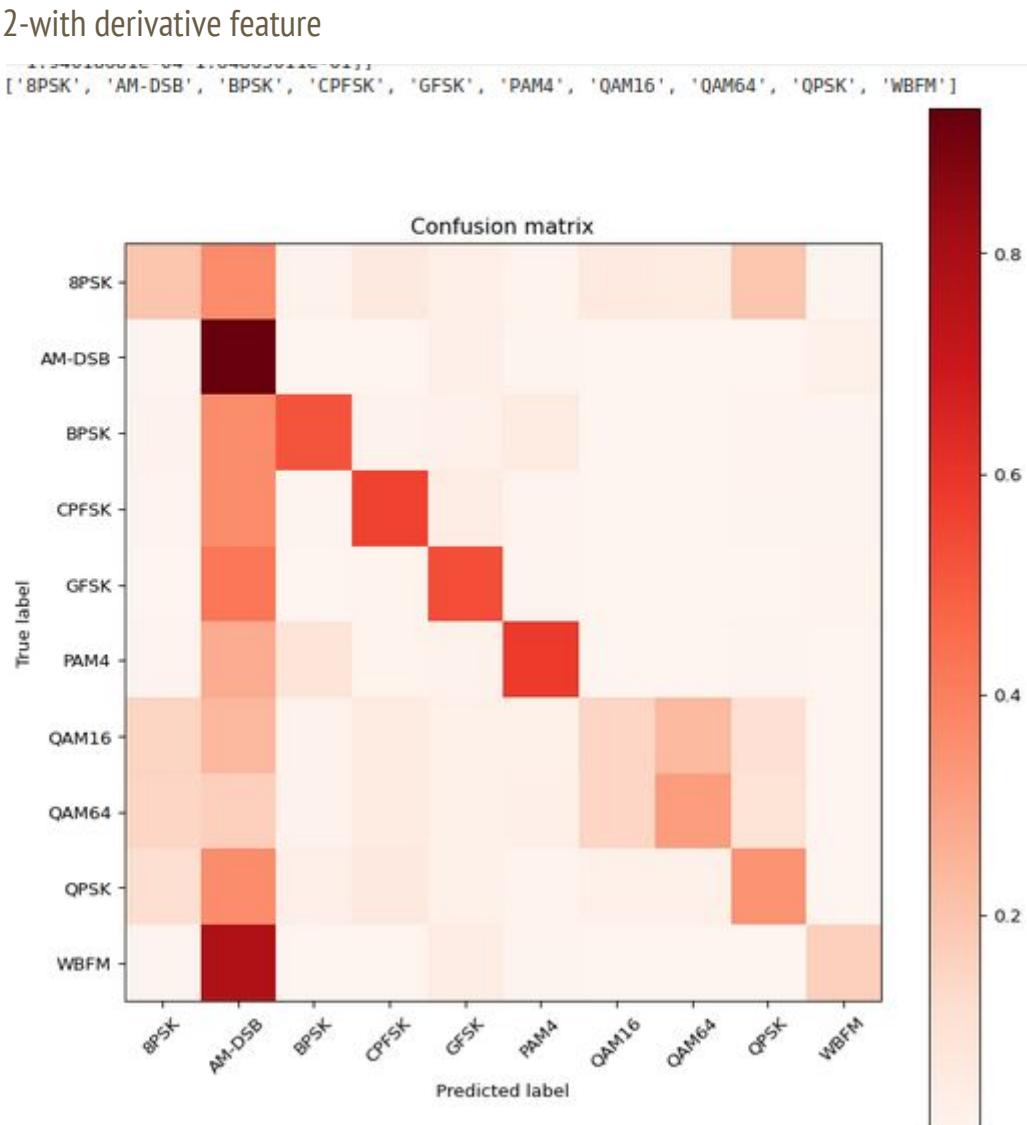
2-with derivative feature

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	9.89	9.88	10.28	10.26	11.17	12.58	16.64	18.89	29.51	45.8	55.96	62.24	66.44	68.91	72.01	74.24	73.58	72.98	71.5	68.24

3-with Integral feature

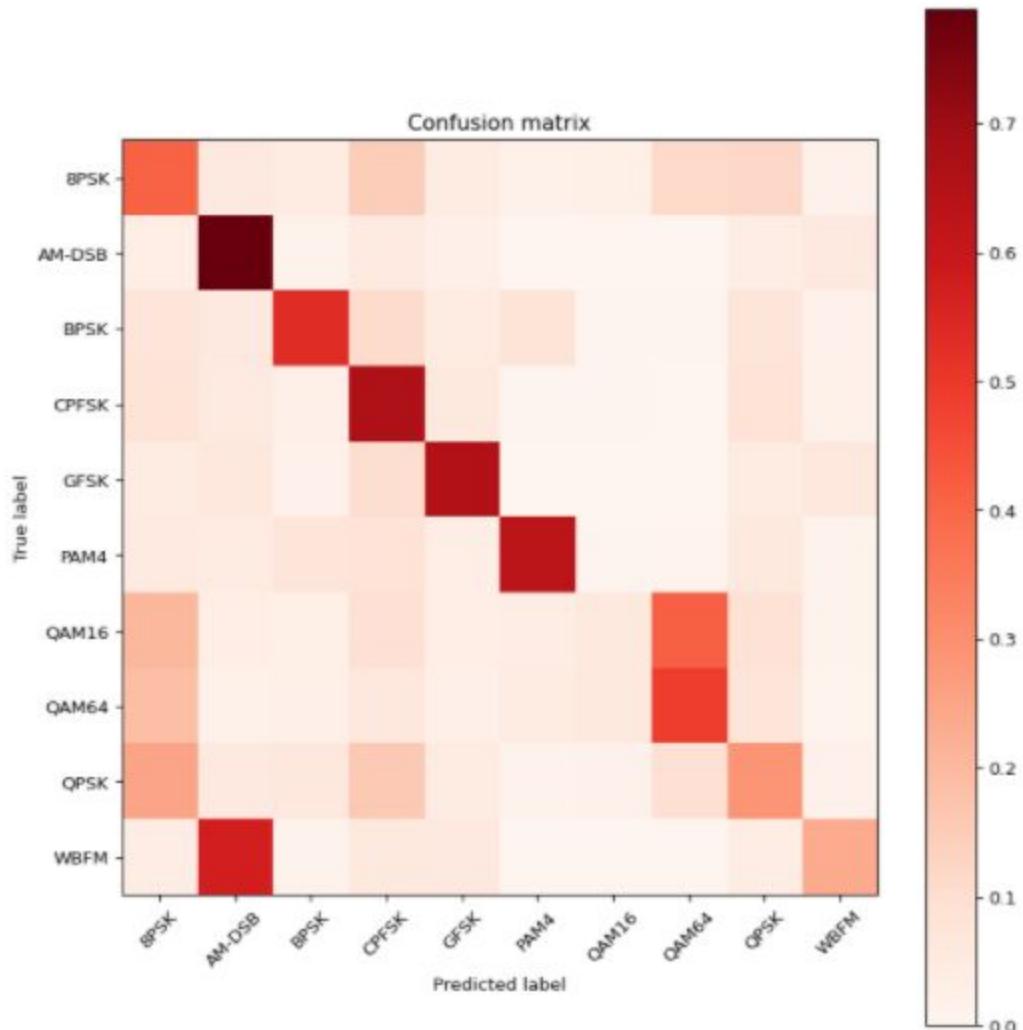
	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.23	10.7	11.65	13.3	17.38	24.9	33.11	42.13	49.69	57.63	63.07	67.08	68.66	68.98	68.88	68.79	68.58	68.65	68.63	68.83







3-with Integral feature



Logistic Regression Classifier

Testing

1-with raw feature

```
Accuracy: 0.16115
[[ 4709 1314 4129 5070 3041 3828 4071 3711 3420 2576]
 [ 1619 16331 1379 1597 1634 1250 1071 1852 1706 7630]
 [ 4490 1227 3943 4997 3079 3903 4112 3980 3513 2658]
 [ 4805 1863 3701 5195 3208 3467 3586 3640 3302 3106]
 [ 4365 4145 2692 4502 4253 2126 2391 3910 3267 4600]
 [ 3999 1968 3622 4523 3066 3667 4091 3946 3331 3787]
 [ 4623 1714 3988 5080 2903 3712 4099 3826 2960 3258]
 [ 4399 1993 3791 5100 2679 3649 4090 3910 2773 3497]
 [ 4691 1293 4044 5115 3111 3866 4104 3681 3430 2578]
 [ 1754 14264 1464 1911 2050 1373 1068 1771 1947 8477]]
precision    recall   f1-score   support
BPSK        0.12     0.13     0.13      35869
AM-DSB      0.35     0.45     0.40      36069
BPSK        0.12     0.11     0.11      35902
CPFSK       0.12     0.14     0.13      35873
GFSK        0.15     0.12     0.13      36251
PAM4        0.12     0.10     0.11      36000
QAM16       0.13     0.11     0.12      36163
QAM64       0.11     0.11     0.11      35881
QPSK        0.12     0.10     0.10      35913
WBFM        0.20     0.23     0.22      36079
accuracy          0.16      360000
macro avg       0.15     0.16     0.16      360000
weighted avg    0.15     0.16     0.16      360000
```

2-with derivative feature

```
Accuracy: 0.1166805555555555
[[3798 3543 3734 4102 3188 3487 3585 3601 3011 3820]
 [4060 5296 3536 3733 3425 3112 2431 2409 3196 4871]
 [3805 3704 3742 4122 3151 3445 3319 3624 3228 3762]
 [3965 3942 3488 4248 3605 3137 3083 3143 3013 4249]
 [3821 4410 3136 3964 4723 2615 2417 2939 3273 4953]
 [3701 3417 3912 4154 3134 3423 3627 3932 3180 3520]
 [3823 2884 3604 4536 3124 3589 3969 4171 2997 3466]
 [3692 2539 3687 4669 3046 3626 4139 4293 3021 3169]
 [3719 3614 3551 4285 3085 3529 3612 3604 3180 3734]
 [4056 5026 3331 3523 3903 3030 2333 2502 3042 5333]]
precision    recall   f1-score   support
BPSK        0.10     0.11     0.10      35869
AM-DSB      0.14     0.15     0.14      36069
BPSK        0.10     0.10     0.10      35902
CPFSK       0.10     0.12     0.11      35873
GFSK        0.14     0.13     0.13      36251
PAM4        0.10     0.10     0.10      36000
QAM16       0.12     0.11     0.12      36163
QAM64       0.13     0.12     0.12      35881
QPSK        0.10     0.09     0.09      35913
WBFM        0.13     0.15     0.14      36079
accuracy          0.12      360000
macro avg       0.12     0.12     0.12      360000
weighted avg    0.12     0.12     0.12      360000
```



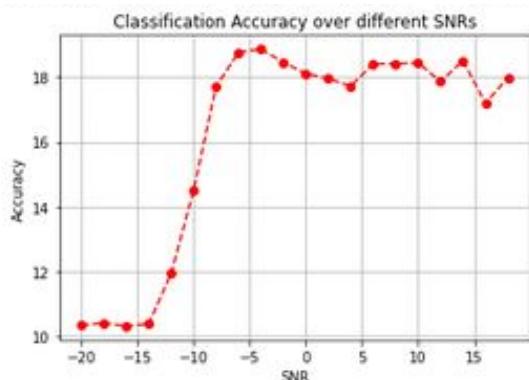
3-with Integral feature

```
Accuracy: 0.1496888888888889
[[ 2374  6778  3575  2245  1847  2200  2079  5006  2296  7469]
 [ 448 20307 1260  405   470   408   396   2395   453  9527]
 [ 2378 7367 3841  2544 1711  2467 1853  4124 2699 6918]
 [ 2176 7022 3800  2410 1747 1995 1720  5385 2305 7313]
 [ 1611 7534 5024 1867 1464 1541 1029 6654 1782 7745]
 [ 2265 8774 4279 2818 1456 2592 1558 3615 2913 5730]
 [ 2292 7116 3629 2241 1722 2184 2004 5398 2299 7278]
 [ 2244 7227 3594 2257 1600 2115 2002 5691 2192 6959]
 [ 2305 6770 3583 2367 1894 2324 1953 4893 2407 7417]
 [ 632 18105 1875 520   514   540   376 2095 624 10798]]
precision    recall   f1-score   support
      BPSK      0.13      0.07      0.09      35869
     AM-DSB      0.21      0.56      0.31      36069
      BPSK      0.11      0.11      0.11      35902
     CPFSK      0.12      0.07      0.09      35873
      GFSK      0.10      0.04      0.06      36251
      PAM4      0.14      0.07      0.10      36000
     QAM16      0.13      0.06      0.08      36163
     QAM64      0.13      0.16      0.14      35881
      QPSK      0.12      0.07      0.09      35913
     WBFM      0.14      0.30      0.19      36079

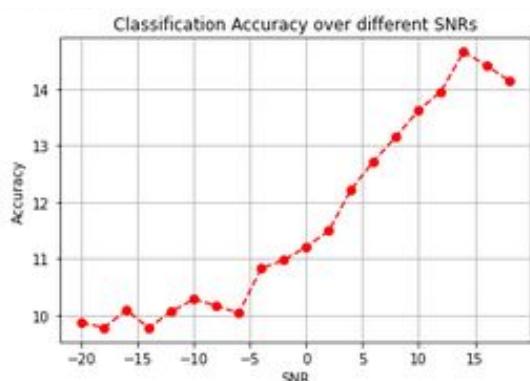
accuracy          0.15      360000
macro avg       0.13      0.15      0.12      360000
weighted avg    0.13      0.15      0.12      360000
```

accuracy against the SNR

1-with raw feature

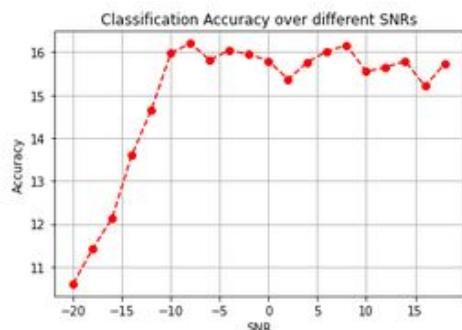


2-with derivative feature





3-with Integral feature



average overall accuracy

1-with raw feature

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.34	10.41	10.32	10.39	11.94	14.5	17.71	18.77	18.87	18.45	18.11	17.96	17.73	18.41	18.42	18.44	17.87	18.51	17.19	17.99

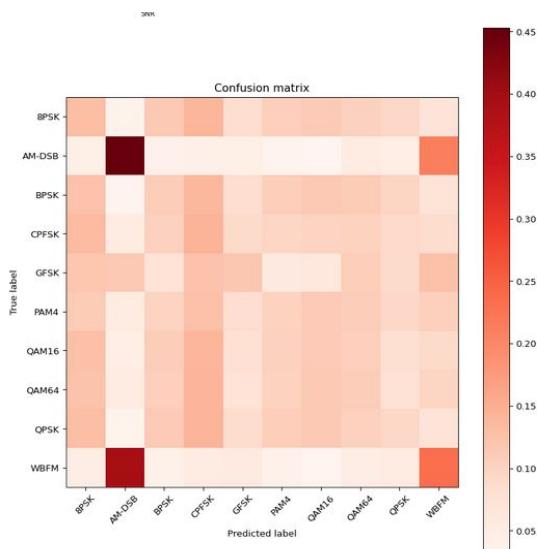
2-with derivative feature

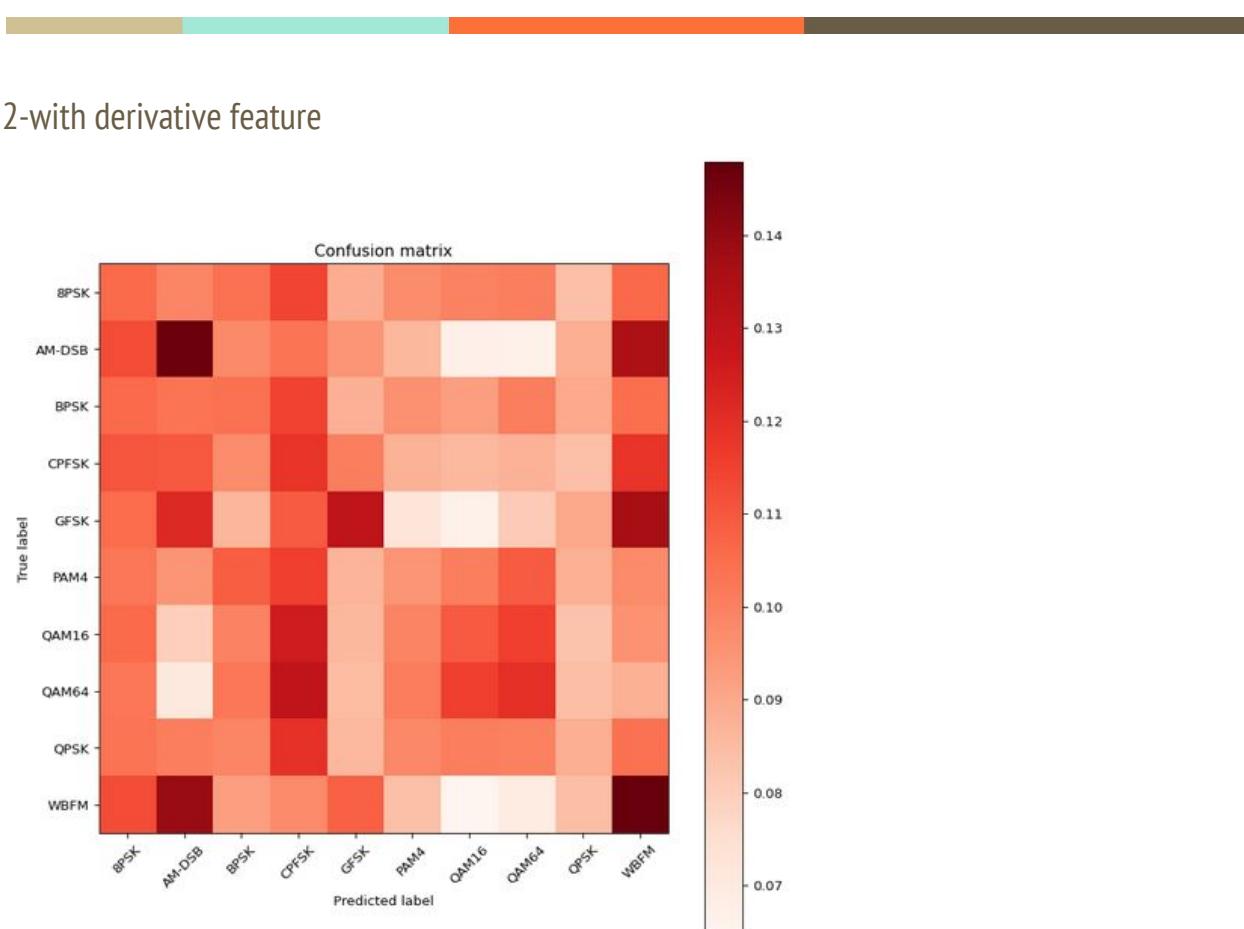
-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	
accuracy	9.87	9.78	10.09	9.77	10.07	10.28	10.17	10.03	10.83	10.97	11.21	11.49	12.23	12.72	13.16	13.62	13.96	14.65	14.41	14.15

3-with Integral feature

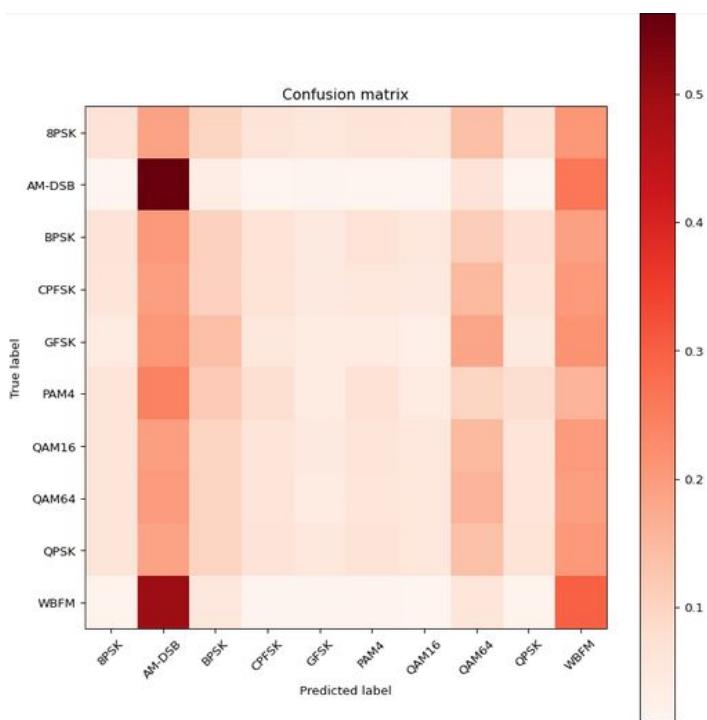
confusion matrices

1-with raw feature





3-with Integral feature



Model Decision Tree

Testing

1-with raw feature

```
Accuracy: 0.3105111111111111
[[ 6544  1709  2901  3109  2748  2496  4642  4699  5242  1779]
 [ 1713 13472  1687  1674  2014  1436  1375  1159  1680  9859]
 [ 3068 1647 12817  2346  2099  3496  2765  2589  3346  1729]
 [ 3342 1591  2189 14242  2608  1810  2608  2387  3330  1766]
 [ 2735 1963  2274 2565 15144  1878  2238  1918  2632  2904]
 [ 2475 1414  3621  1971 1903 14296  3222  3300  2400  1398]
 [ 4741 1347  2757 2628 2159  3218  6667  7141  4022  1483]
 [ 4734 1150  2494 2273 1974  3114  7011  8062  3880  1189]
 [ 5288 1657  3408 3311 2604  2255  3930  3757  7961  1742]
 [ 1844 9505  1741 1776 2834 1401 1444  1237 1718 12579]]
precision    recall   f1-score   support
BPSK        0.18      0.18      0.18      35869
AM-DSB      0.38      0.37      0.38      36069
BPSK        0.36      0.36      0.36      35902
CPFSK       0.40      0.40      0.40      35873
GFSK        0.42      0.42      0.42      36251
PAM4        0.40      0.40      0.40      36000
QAM16       0.19      0.18      0.19      36163
QAM64       0.22      0.22      0.22      35881
QPSK        0.22      0.22      0.22      35913
WBFM        0.35      0.35      0.35      36079
micro avg   0.31      0.31      0.31      360000
macro avg   0.31      0.31      0.31      360000
weighted avg 0.31      0.31      0.31      360000
samples avg  0.31      0.31      0.31      360000
```

2-with derivative feature

```
Accuracy: 0.1761694444444443
[[ 4313  3341  3158  2849  2936  2988  4444  4479  4151  3210]
 [ 3340 5608  3392  3474  4016  2943  2580  2217  3343  5164]
 [ 3150 3482  6473  2703  2986  5034  2870  2666  3242  3296]
 [ 2947 3329  2638 10392  3123  2415  2597  2318  2831  3282]
 [ 3147 4136  2969  3264  7423  2692  2866  2609  3016  4129]
 [ 3042 3042  5107  2421  2626  7722  3085  3098  2960  2897]
 [ 4433 2585  2883  2466  2762  3151  5183  5724  4367  2609]
 [ 4655 2169  2716  2265  2533  3127  5582  6249  4392  2193]
 [ 4332 3338  3161  2832  2916  3021  4352  4316  4450  3195]
 [ 3334 5269  3376  3260  4188  2938  2587  2315  3196  56161]]
precision    recall   f1-score   support
BPSK        0.12      0.12      0.12      35869
AM-DSB      0.15      0.16      0.15      36069
BPSK        0.18      0.18      0.18      35902
CPFSK       0.29      0.29      0.29      35873
GFSK        0.21      0.20      0.21      36251
PAM4        0.21      0.21      0.21      36000
QAM16       0.14      0.14      0.14      36163
QAM64       0.17      0.17      0.17      35881
QPSK        0.12      0.12      0.12      35913
WBFM        0.16      0.16      0.16      36079
micro avg   0.18      0.18      0.18      360000
macro avg   0.18      0.18      0.18      360000
weighted avg 0.18      0.18      0.18      360000
samples avg  0.18      0.18      0.18      360000
```

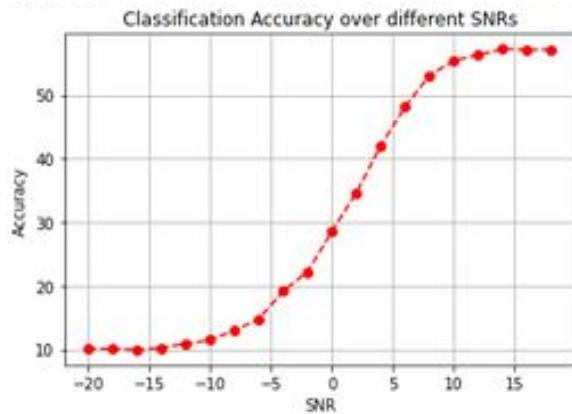
3-with Integral feature

```
Accuracy: 0.2596777777777778
[[ 4992  1358  3057  4395  2833  2955  4889  5026  4878  1494]
 [ 1417 15397 1182 1341 1698 1087 1245 1328 1309 10665]
 [ 3238 1168 9913 2707 1838 6371 3083 3056 3292 1236]
 [ 4384 1276 2628 7494 3540 2433 4140 4275 4313 1390]
 [ 2762 1606 1679 3661 14134 1771 2669 2655 2712 2602]
 [ 2949 1135 6586 2525 1680 10890 3077 2995 2956 1207]
 [ 4839 1287 2916 4298 2761 2961 5390 5537 4751 1423]
 [ 4849 1137 2801 4337 2722 2831 5255 5733 4864 1352]
 [ 4840 1304 3415 4547 2796 2868 4702 4863 5097 1481]
 [ 1498 9496 1162 1523 2685 1083 1448 1323 1417 14444]]
precision    recall   f1-score   support
      8PSK      0.14      0.14      0.14      35869
     AM-DSB      0.44      0.43      0.43      36069
      BPSK      0.28      0.28      0.28      35902
     CPFSK      0.20      0.21      0.21      35873
      GFSK      0.39      0.39      0.39      36251
      PAM4      0.31      0.30      0.31      36000
     QAM16      0.15      0.15      0.15      36163
     QAM64      0.16      0.16      0.16      35881
      QPSK      0.14      0.14      0.14      35913
      WBFM      0.39      0.40      0.40      36079

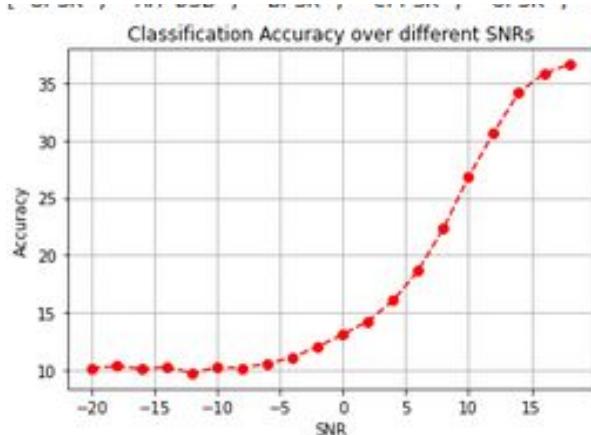
   micro avg      0.26      0.26      0.26      360000
   macro avg      0.26      0.26      0.26      360000
weighted avg      0.26      0.26      0.26      360000
samples avg      0.26      0.26      0.26      360000
```

accuracy against the SNR

1-with raw feature

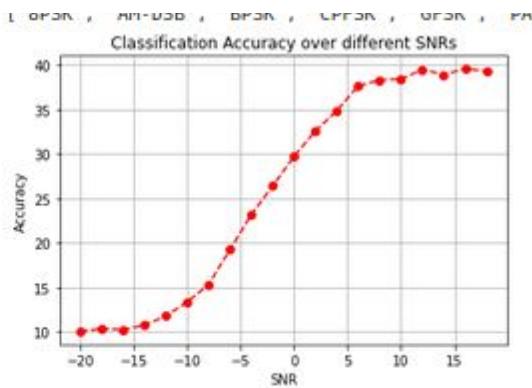


2-with derivative feature





3-with Integral feature



average overall accuracy

1-with raw feature

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.07	10.11	9.93	10.25	10.9	11.47	12.99	14.79	19.17	22.25	28.55	34.66	42.02	48.17	53.09	55.45	56.3	57.28	57.14	57.18

2-with derivative feature

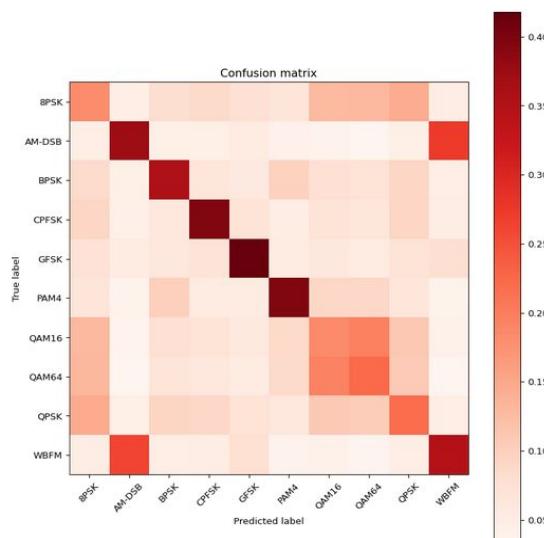
-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18

3-with Integral feature

-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	
accuracy	10.13	10.33	10.07	10.24	9.71	10.21	10.15	10.52	11.09	12.02	13.09	14.24	16.03	18.68	22.33	26.83	30.67	34.18	35.84	36.62

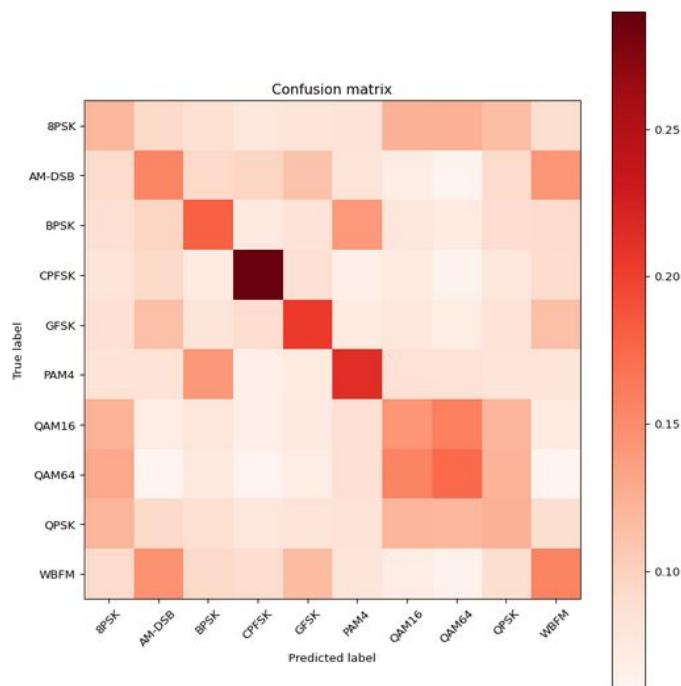
confusion matrices

1-with raw feature





2-with derivative feature



3-with Integral feature

