Analyzing Hardware Constraints of Gabor Filtering Operation for Facial Expression Recognition System

Sumeet Saurav, Ravi Saini, Sanjay Singh, Anil K Saini
IC Design Group
CSIR-Central Electronics Engineering Research Institute
Pilani, Rajasthan, India
sumeetssaurav@gmail.com

Nidhi Sharma
AIM & ACT
Banasthali Vidhyapeeth
Tonk, Rajasthan, India

***Abstract*—This paper presents hardware constraints analysis of Gabor filtering operation for its hardware implementation in a real time Facial Expression Recognition System (FERS). Gabor filter is the most common feature extractor employed for the realization of such system. Feature extraction using Gabor filter is efficient and has better discrimination capability. In this work, we have employed software-based approach to find the optimum filter and facial image size. These two factors employed in the Gabor filtering process directly affect the hardware resource utilization and hence we have considered these two factors for our analysis. We have used two versions of Gabor filter for feature extraction, one using the original Gabor filtering approach and the other its modified version using Image Pyramid based approach. Support Vector Machine (SVM) classifier has been used for analyzing the performance of the extracted feature.**

Keywords—Gabor filter; Image Pyramid; PCA; AdaBoost; Support Vector Machine (SVM).

I. INTRODUCTION

Facial expressions are the means of non-verbal communication in human beings. It has numerous applications in areas such as video conferencing, user profiling, image retrieval, psychological analysis, face animation, etc. Although, software implementation of facial expression recognition system is feasible, but it suffers from real-time constraints. In order to overcome this limitation its hardware implementation is necessary and hence it is one of the active fields of research among the researches of the Computer Vision community. Basically, a facial expression recognition system consists of face detection, feature extraction, feature selection and classification. Face detection step is used to obtain the face region from images. Feature extraction involves simplifying the amount of resource required to describe the large set of data obtained from the extracted faces accurately. For the further reduction of the computational complexity feature reduction/selection step is usually performed. Finally, using the reduced features expressions are classified using Support Vector Machine classification approach [1].

The main objective of this work is to analyze the hardware constraints of Gabor filtering operation for its hardware implementation in a real time facial expression recognition system. Here, we have considered three expressions (neutral, happy and sad) for our analysis. We have used Gabor filter for feature extraction, due to its application in various fields such as computer vision, image processing and pattern recognition. The filter also possesses spatial localization, orientation selectivity and spatial frequency characteristics. However, the most important advantage of Gabor filter is their invariance to illumination, rotation, scale, and translation [2]. In [3], the authors have performed texture feature extraction of skull-stripped images using 2-D Gabor filter. The authors in [4], described the compact representation of texture features using scale and rotation invariant Gabor filters. For the purpose of finger print image enhancement Gabor filtering technique has been used in [5]. In [6], the authors have discussed software based approach for facial expression recognition. In this work Gabor filter has been used for extraction of features from the image patches located by the face detector. The authors in [7], have implemented a configurable architecture for multi-resolution Gabor feature extraction that enhances the resource utilization of hardware fabric. Coarse to fine grain technique has been used by the authors in [8] for the purpose of implementing Gabor filtering architecture for applications in which large numbers of filters are required corresponding to a number of orientations.

The rest part of paper is organized as: section II gives a brief introduction of Gabor filter and describes feature extraction using the original Gabor filtering approach and image pyramid based approach. Section III presents the database preparation required for performing our experiments. In section IV, results of the analysis are presented and discussed which is followed by conclusion in section V.

II. GABOR FILTERS

In the spatial domain, a two-dimensional Gabor filter is a Gaussian kernel function modulated by a complex sinusoidal plane wave, defined by eq. (1) [2].

$$G(x,y) = \frac{f^2}{\pi\gamma\eta}\exp\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right)\exp\left(j2\pi fx'+\phi\right) \quad (1)$$

where

$$x' = x\cos(\theta) + y\sin(\theta)$$
$$y' = -x\sin(\theta) + y\cos(\theta)$$

In (1), f is the frequency of the sinusoidal factor, θ represents the orientation of the normal to the parallel strips of a Gabor function, ϕ is the phase effect, σ is the standard deviation of the Gaussian envelope and γ is the spatial aspect ratio which specifies the ellipticity of the support of the Gabor function. The scales and orientations are changed according to (2).

$$f_g = \frac{f_{max}}{\left(\sqrt{2}\right)^g}$$
$$f_{max} = 0.25 \quad and \quad g \in \{0,1,2,3,4\} \qquad (2)$$
$$\theta_h = \frac{h}{8}\pi, h \in \{0,1,2,3,4,5,6,7\}$$

$$\gamma = \eta = \sqrt{2}$$

A. *Feature Extraction Using Original Gabor Filtering Approach*

Gabor filter bank consisting of multiple filters tuned to different orientations and frequencies are convolved with the input face image. Here, we have used 40 Gabor filters corresponding to 8 orientations and 5 frequencies as shown in (1). The total number of features extracted using this approach are 40960 and 10240 for an image size 128x128 and 64x64 respectively and is obtained by multiplying the image (128x128) with number of scales and orientations (5x8) and then dividing the resultant with the row-column down-sampling factor (4x4) as shown in [2]. From this large pool of features significant features are extracted using feature selection/reduction algorithms (AdaBoost/PCA).

B. *Feature Extraction Using Image Pyramid Based Approach*

In this approach, only 8 Gabor filters corresponding to 8 orientations are used. The major difference between this approach and the original approach is that, in the original approach the input image is convolved with 40 Gabor filters corresponding to 8 orientations and 5 scales, whereas in this approach the input image itself is scaled and then convolved with only 8 Gabor filters corresponding to 8 different orientations. For image scaling, Gaussian pyramid based approached has been used. The total numbers of features generated using this approach are 10912 and 2728 for image of size 128x128 and 64x64 respectively. Here also, significant features are extracted using feature selection/reduction algorithm (AdaBoost/ PCA).

III. DATABASE PREPARATION

We have used our own database consisting of 56 neutral, 77 happy and 49 pain faces of different individual for the purpose of training and testing using image size of 128 by 128. The distribution of the database into train and test sets has been shown in table I and sample images are shown in the Fig 1. For the image of size 64x64 we have used 60 neutral, 66 happy and 143 pain images. The distribution of test and train images has been shown in table II. For extracting the faces we have used Viola and Jones face detection framework.

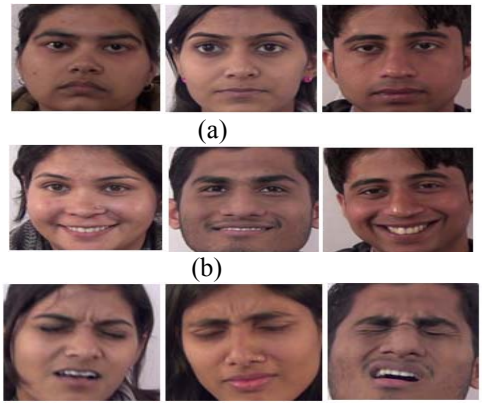

Fig. 1. Training samples of the three classes used in our system: (a) Neutral (b) Happy (c) Pain

TABLE I. DISTRIBUTION OF TRAINING AND TEST DATABASE FOR IMAGE SIZE (128X128)

S. No.	Expressions	Training set size	Test set size
1	Neutral	40	16
2	Happy	55	22
3	Pain	40	09

TABLE II. DISTRIBUTION OF TRAINING AND TEST DATABASE FOR IMAGE SIZE (64X64)

S. No.	Expressions	Training set size	Test set size
1	Neutral	40	20
2	Happy	44	22
3	Pain	71	72

IV. RESULTS AND DISCUSSION

All the algorithms ranging from Gabor filters to AdaBoost including PCA has been coded using Matlab. For classification using different types of SVM classifiers we have used LibSVM library in the Matlab environment.

A. *Original Gabor Filter Based Approach*

The analysis result of the features extracted by the Gabor filter with image size of 128 x 128 and filters of different kernel sizes has been shown in table III-table VIII. Significant features have been selected using AdaBoost/PCA feature selection algorithm. Tables also show the accuracy of the selected features using different SVM classifiers.

From the tables, we find that with an image size of 128x128 and filter size of 21x21 an accuracy of 97.87% has

been achieved using both OAO-L and OAO-NL support vector machine classifier when features were selected using AdaBoost. The same accuracy has also been achieved with PCA reduced dataset using the similar image and filter size. Moreover, using similar image size with filter size of 11x11, the maximum accuracy achieved in the case of AdaBoost selected features is 97.87% using both OAO-L and OAO-NL classifier and that of PCA is 93.62% using OAO-NL, OAA-L and OAA-NL support vector machine classifier. Using the filter size of 5x5, the maximum accuracy achieved with AdaBoost reduced features is 93.62 % and that using PCA is 87.23 %.

TABLE III. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 21X 21 USING ADABOOST WITH IMAGE SIZE 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	49	$1x10^{-2}$	-	97.87	46 42 44
OAO-NL		50	$2x10^{-3}$	97.87	29 26 23
OAA-L		$5x10^{-3}$	-	95.74	57 64 57
OAA-NL		50	$2x10^{-2}$	93.62	44 60 54

TABLE IV. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 21X 21 USING PCA WITH IMAGE SIZE 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	40	$1x10^{-3}$	-	97.87	45 38 41
OAO-NL	40	100	$1x10^{-6}$	97.87	47 46 47
OAA-L	20	$1x10^{-3}$	-	97.87	28 39 32
OAA-NL	30	100	$3x10^{-6}$	97.87	37 39 36

TABLE V. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 11X 11 USING ADABOOST WITH IMAGE SIZE 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	52	$1x10^{-2}$	-	97.87	47 44 45
OAO-NL		100	$1x10^{-4}$	97.87	41 36 39
OAA-L		$1x10^{-5}$	-	95.74	80 110 80
OAA-NL		100	$1x10^{-2}$	95.74	33 52 36

TABLE VI. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 11X 11 USING PCA WITH IMAGE SIZE 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	70	$1x10^{-3}$	-	91.48	61 49 60
OAO-NL	30	100	$1x10^{-5}$	93.62	48 48 48
OAA-L	30	$1x10^{-2}$	-	93.62	31 28 30
OAA-NL	70	500	$1x10^{-6}$	93.62	46 57 57

TABLE VII. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 5X 5 USING ADABOOST WITH IMAGE SIZE 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	75	$1x10^{-2}$	-	91.48	61 53 56
OAO-NL		100	$1x10^{-2}$	93.62	70 64 70
OAA-L		$1x10^{-3}$	-	93.62	87 114 84
OAA-NL		100	$1x10^{-6}$	93.62	86 113 85

TABLE VIII. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 5X 5 USING PCA WITH IMAGE SIZE 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	90	$1x10^{-4}$	-	80.85	73 64 71
OAO-NL	90	100	$1x10^{-8}$	80.85	71 60 67
OAA-L	40	$1x10^{-8}$	-	85.11	80 110 80
OAA-NL	60	100	$1x10^{-11}$	87.23	80 110 80

Thus, for the image size of 128x128, the maximum accuracy obtained is 97.87 % using filter size of 21x21 and 11x11.

Next, we changed the image size to 64x64 and performed similar analysis with different filter kernels. The analysis result has been shown in table IX-table XIV. From the tables, we find that, with filter size of 21x21 the maximum accuracy of 92.68% is achieved using AdaBoost selected features using OAO-NL support vector machine classifier. However, using PCA the accuracy gets increased to 93.62 % using OAA-NL

support vector machine classifier. With filter size of 11x11 using AdaBoost the maximum accuracy achieved is 87.71 % with OAO-NL support vector machine classifier. The maximum accuracy with PCA reduced features is 86.84 % obtained using OAA-NL support vector machine classifier for the same filter size. Finally, using filter size of 5x5 the maximum accuracy achieved using AdaBoost selected feature is 87.72 % with OAA-NL support vector machine classifier. However, using the PCA reduced feature the maximum accuracy obtained is 85.90 % using OAA- NL support vector machine classifier. Thus, for the image size of 64x64, the maximum accuracy achieved is 93.62 % using OAA-NL support vector machine classifier with PCA reduced features.

TABLE IX. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 21X 21 USING ADABOOST WITH IMAGE SIZE 64X64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	64	$1x10^{-1}$	-	90.24	34 41 37
OAO-NL		100	$9x10^{-4}$	91.46	36 44 38
OAA-L		$9x10^{-1}$	-	92.68	21 33 33
OAA-NL		200	$1x10^{-4}$	90.24	34 40 42

TABLE X. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 21X 21 USING PCA WITH IMAGE SIZE 64X64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	90	$46x10^{-5}$	-	89.02	67 81 86
OAO-NL	90	200	$3x10^{-5}$	92.68	66 83 85
OAA-L	100	$9x10^{-4}$	-	89.02	68 67 72
OAA-NL	100	100	$5x10^{-5}$	93.62	98 109 99

TABLE XI. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 11X 11 USING ADABOOST WITH IMAGE SIZE 64X64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	56	$1x10^{-1}$	-	86.84	34 34 36
OAO-NL		100	$1x10^{-2}$	87.71	49 50 53
OAA-L		$1x10^{-2}$	-	85.09	49 59 54
OAA-NL		100	$1x10^{-2}$	86.84	39 57 51

TABLE XII. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 11X 11 USING PCA WITH IMAGE SIZE 64X64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	100	$2x10^{-4}$	-	81.57	73 79 84
OAO-NL	100	100	$1x10^{-5}$	83.53	65 71 74
OAA-L	90	$1x10^{-3}$	-	84.21	55 55 59
OAA-NL	90	100	$1x10^{-6}$	86.84	76 88 84

TABLE XIII. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 5X 5 USING ADABOOST WITH IMAGE SIZE OF 64X64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	77	$6x10^{-2}$	-	86.84	42 39 43
OAO-NL	77	100	$1x10^{-5}$	85.96	79 82 89
OAA-L	77	$2x10^{-3}$	-	84.21	84 93 93
OAA-NL	77	100	$1x10^{-2}$	87.72	54 65 67

TABLE XIV. ANALYSIS OF ORIGINAL GABOR FILTER OF SIZE 5X 5 USING PCA WITH IMAGE SIZE OF 64X64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	40	$1x10^{-3}$	-	80.70	52 52 52
OAO-NL	40	200	$1x10^{-6}$	84.21	62 63 63
OAA-L	60	$1x10^{-3}$	-	85.09	53 59 46
OAA-NL	60	100	$1x10^{-5}$	85.09	54 58 49

B. Gabor filter using image pyramid based approach

Features that are extracted by image pyramid based Gabor filtering approach using image size of 128x128 with filter size of 21x21 and reduced by AdaBoost achieved an accuracy of 89.36 % with OAO linear SVM. When the same features are classified using OAO non-linear SVM we got an accuracy of 91.48 %. Similarly, for OAA-L and OAA-NL support vector machine the accuracy obtained is 89.36 % and 91.49 % respectively. The result obtained has been show in table XV.

Using the similar approach with PCA reduced features we obtained an accuracy of 95.74 % with OAO-L and an accuracy

of 97.87 % with OAO-NL support vector machine classifier. Similarly, with OAA-L and OAA-NL an accuracy of 97.87 % has been achieved. The detailed analysis result has been shown in the table XVI.

TABLE XV. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 21X 21 USING ADABOOST WITH IMAGE SIZE OF 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	74	$1x10^{-2}$	-	89.36	64 53 65
OAO-NL		100	$2x10^{-2}$	91.48	60 50 64
OAA-L		$9x10^{-1}$	-	89.36	40 35 36
OAA-NL		100	$1x10^{-2}$	91.49	81 82 79

TABLE XVI. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 21X 21 USING PCA WITH IMAGE SIZE OF 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	70	$1x10^{-1}$	-	95.74	62 52 62
OAO-NL	20	25	$9x10^{-5}$	97.87	48 40 48
OAA-L	20	$1x10^{-2}$	-	97.87	43 53 44
OAA-NL	20	10	$1x10^{-4}$	97.87	47 62 56

Next, we changed the filter size to 11x11 and performed similar analysis using both AdaBoost and PCA. With AdaBoost selected features we obtained a maximum accuracy of 95.74 % using OAO-L support vector machine classifier. The OAO-NL, OAA-L and OAA-NL support vector machine classifiers provided an accuracy of 97.87 %. The analysis results have been shown in the table XVII.

TABLE XVII. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 11X 11 USING ADABOOST WITH IMAGE SIZE OF 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	76	$1x10^{-2}$	-	95.74	62 54 58
OAO-NL		30	$2x10^{-2}$	97.87	79 75 80
OAA-L		$2x10^{-3}$	-	97.87	79 97 84
OAA-NL		100	$1x10^{-5}$	97.87	79 97 84

The analysis result using the same image and filter size with PCA reduced features has been shown in the table XVIII. From the table, we find that with 30 features obtained using PCA an accuracy of 95.74% has been achieved using both OAO-L and OAO-NL support vector machine classifier. Likewise features classified using OAA-L, provided a maximum accuracy of 97.87%, whereas an accuracy of 95.74% has been obtained using OAA-NL support vector machine classifier.

Finally, we reduced the filter size to 5x5 keeping the image size same and performed the analysis using both AdaBoost and PCA with all the four support vector machine classifiers. With AdaBoost selected features we obtained an accuracy of 74.46 % using OAO-L support vector machine and an accuracy of 82.97 % with its non-linear variant. Similarly, using OAA-L classification strategy we obtained an accuracy of 78.72 %, whereas with OAA-NL support vector machine approach we obtained an accuracy of 85.11 %. The result showing the margin parameter and support vectors have been shown in table XIX.

TABLE XVIII. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 11X 11 USING PCA WITH IMAGE SIZE OF 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	30	$2x10^{-3}$	-	95.74	47 39 42
OAO-NL	40	100	$1x10^{-5}$	95.74	49 47 48
OAA-L	30	$4x10^{-3}$	-	97.87	41 37 35
OAA-NL	20	100	$1x10^{-5}$	95.74	38 57 42

TABLE XIX. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 5X5 USING ADABOOST WITH IMAGE SIZE OF 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	86	$1x10^{-1}$	-	74.46	45 44 45
OAO-NL		100	$1x10^{-4}$	82.97	58 54 56
OAA-L		$1x10^{-4}$	-	78.72	85 113 85
OAA-NL		100	$1x10^{-4}$	85.11	51 53 58

Features that are extracted by image pyramid based Gabor filtering approach using image and filter size and reduced by PCA technique achieved a maximum accuracy of 82.97% using OAO-L support vector machine classifier with 90 features. On the other hand, with only 20 features obtained using PCA we obtained a maximum accuracy of 80.85% using

OAO-NL support vector machine classifier. This has been shown in table XX.

TABLE XX. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 5X5 USING PCA WITH IMAGE SIZE OF 128X128

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	90	$1x10^{-3}$	-	82.97	73 65 74
OAO-NL	20	10	$1x10^{-5}$	80.85	71 66 73
OAA-L	90	$1x10^{-6}$	-	89.36	96 122 97
OAA-NL	80	100	$1x10^{-6}$	87.23	80 95 86

The analysis result of features extracted using image pyramid based approach for the image size of 64 X 64 and filter size of 21 x 21 has been shown in table XXI. Here, with AdaBoost selected feature we obtained an accuracy of 77.19 % using OAO-L and 80.70 % using OAO-NL support machine classifiers. On the other hand, with OAA-L an accuracy of 78.95 % is obtained and that with OAA-NL support vector machine classifier we obtained an accuracy of 78.07 %.

TABLE XXI. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 21X21 USING ADABOOST WITH IMAGE SIZE 64 X 64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	89	$9x10^{-3}$	-	77.19	57 59 66
OAO-NL		10	$9x10^{-5}$	80.70	53 55 62
OAA-L		$2x10^{-3}$	-	78.95	80 96 111
OAA-NL		100	$1x10^{-5}$	78.07	80 96 111

With, features reduced using PCA for the same image and filter size using the similar approach, we obtained a maximum accuracy of 84.21% using both OAO-L and OAO-NL support vector machine classifier. The number of features used is 100 for OAO-L and 80 for OAO-NL. On the other hand, a maximum accuracy of 87.72 % has been obtained using both OAA-L and OAA-NL support vector machine classifiers. The number of features used in this case is 100 and 90 respectively for OAA-L and OAA-NL. The detailed analysis result has been shown in table XXII. From the table we also find that, for the same number of features OAA-L achieved better accuracy than OAO-L support vector machine classifier.

TABLE XXII. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 21X21 USING PCA WITH IMAGE SIZE 64 X 64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	100	$9x10^{-4}$	-	84.21	73 82 83
OAO-NL	80	100	$1x10^{-4}$	84.21	72 80 80
OAA-L	100	$96x10^{-5}$	-	87.72	78 94 84
OAA-NL	90	90	$1x10^{-5}$	87.72	60 79 77

Features that are extracted using image pyramid based Gabor filtering approach using image size of 64 x 64 and filter size of 11 x 11 with AdaBoost based feature selection strategy achieved a maximum accuracy of 84.21 % using both OAO-L and OAO-NL support vector machine classifier. However, with OAA-L and OAA-NL support vector machine classifier a maximum accuracy of 87.72 % has been obtained. The results have been shown in table XXIII.

TABLE XXIII. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 11X11 USING ADABOOST WITH IMAGE SIZE 64 X 64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	88	$3x10^{-3}$	-	84.21	69 81 88
OAO-NL		25	$1x10^{-4}$	81.57	61 73 80
OAA-L		$1x10^{-2}$	-	81.58	50 66 66
OAA-NL		10	$2x10^{-4}$	84.21	63 79 86

With the PCA reduced feature set a maximum accuracy of 86.84 % has been achieved using OAA-L support vector machine classifier. The performance of other classifiers has been shown in table XXIV.

TABLE XXIV. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 11X11 USING PCA WITH IMAGE SIZE 64 X 64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	70	$5x10^{-4}$	-	82.45	75 88 91
OAO-NL	90	30	$1x10^{-5}$	83.33	72 90 92
OAA-L	90	$1x10^{-3}$	-	86.84	72 88 78
OAA-NL	60	10	$1x10^{-4}$	85.09	69 77 72

For our final analysis, we changed the filter size to 5x5 and repeated the experiments. Features that are extracted by this version of the Gabor filter using image size of 64x64 and filter size of 5x5 reduced by AdaBoost provided a maximum accuracy of 77.20 % with OAO-NL support vector machine classifier. The detailed analysis result has been shown in the table XXV. On the other hand, with the PCA reduced features we obtained a maximum accuracy of 74.56 % using OAA-L support vector machine classifier. The analysis result showing the performance of other classifiers has been shown in table XXVI.

TABLE XXV. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 5X5 USING ADABOOST WITH IMAGE SIZE 64 X 64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	105	$1x10^{-2}$	-	74.56	66 66 72
OAO-NL		23	$1x10^{-4}$	77.20	76 82 86
OAA-L		$1x10^{-2}$	-	74.56	67 77 71
OAA-NL		10	$1x10^{-6}$	71.93	85 91 142

TABLE XXVI. ANALYSIS RESULT OF IMAGE PYRAMID BASED GABOR FILTER OF SIZE 5X5 USING PCA WITH IMAGE SIZE 64 X 64

SVM	No. features	C	γ	Accuracy (%)	No. SVs
OAO-L	60	$9x10^{-4}$	-	71.92	69 73 78
OAO-NL	60	50	$1x10^{-5}$	71.05	67 72 77
OAA-L	30	$1x10^{-1}$	-	74.56	35 52 28
OAA-NL	40	300	$1x10^{-5}$	72.81	53 59 46

V. CONCLUSION

In this work, we analyzed the accuracy of Gabor filter with the different feature selection/reduction (AdaBoost/PCA) and classification techniques (SVM). The performance comparison of these techniques is carried out on the basis of classification accuracy. After analyzing both form of Gabor filtering using original approach and the modified one using image pyramid based approach, we observed that using both AdaBoost and PCA the original Gabor filtering approach achieved a maximum accuracy of 97.87% using OAO-L support vector machine classifier for image of size 128x128 with filter of size 21x21. With the features extracted using the image pyramid based approach we found that both AdaBoost and PCA also provided a maximum accuracy of 97.87% for OAO-NL support vector machine with image size of 128x128 and filter size 11x11. For the ease of hardware implementation and reduction in resource utilization, feature extraction with Gabor filter using image pyramid based approach is observed to be more efficient compared to the original Gabor filtering approach since it involves only 8 convolution operation at each image pyramid level and all the filter coefficients are the same at each level. However, in the original Gabor filtering approach the original image is convolve with 40 different filter kernels which requires huge amount of computation and storage.

Regarding feature reduction/selection we found that both PCA/AdaBoost provided approximately the same accuracy when tested over various image and filter sizes. However, with hardware point of view, AdaBoost is preferred over PCA, since when using AdaBoost we only need to store the indices corresponding to the selected features, but in PCA we need to have dedicated architecture to perform the dimensionality reduction on the features obtained after the Gabor filtering stage. For the classification technique we found that OAO-L and OAO-NL support vector machine classifier performed better compared to their OAA variants.

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