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An FPGA-Based Implementation of Emotion Recognition Using EEG Signals

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Abstract: ***An electroencephalogram is a machine that uses small metal discs (electrodes) placed on the scalp to detect all the electrical activity in the human brain. Electric impulses connect the brain cells and are active at all times and even while we are sleeping. This activity appears as wavy lines on the EEG recording. The preprocess function filters data to a frequency range of 0 to 75 Hz. It creates a new matrix with a sampling rate of 200Hz and a range of 0 to 75Hz. The Low pass filter of Finite Impulse Response was utilized. Because bandpass would make the EEG data unstable after processing. Each EEG pre-processed signal has output, completing the feature extraction. Principal Component Analysis, or PCA, is used in the feature reduction phase. PCA is a statistical process that turns around a correlated set of features into mutually uncorrelated features, or principal components, using singular value decomposition. Principal Components Analysis: (1) Mean normalization of features (2) Covariance Matrix (3) Eigen Vectors (4) Reduced features or principal components. The preceding step's PCs will be passed into the SVM classifier for emotion output. A VHDL code & testbench for a 2*2 matrix was written and the waveform, RTL schematic was obtained on Xilinx 14.5. For the FPGA implementation, the Simulink Model was designed and the eigen values were computed using a system generator.***

Keywords: Electroencephalography, Principal Component Analysis, Support Vector Machine, Eigenvector Calculation

1.Introduction

While the human emotional state is important in daily life, the scientific aspect of human emotional responses is still quite restricted. When pieces of machinery are incorporated into the system that helps recognize these emotions, productivity and expenditures are improved in a variety of ways. Emotion is a psychological phenomenon mediated by the individual's need urge, consisting of consist of the following: increased heart rate, subjectivity, and performance in the outside world. The response to emotions is referred to as arousal. While content or cheerful, the heartbeat slows down, blood pressure increases, breathing rate increases, and even an intermittent or stop occurs; when painful, blood vessel volume reduces. According to relevant studies, women are more prone to elicit emotions than males, and the level of physiological reactions is greater.

The most frequent classification employs the EEG waveform frequency band, which allows EEG signals to be divided into five distinct frequency bands. As a result, the five distinct frequency bands, as well as the mental states connected with them, are briefly discussed below.

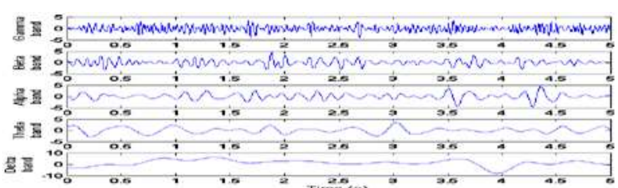

Figure 1: Various frequency bands in EEG signals

Delta: a wavelength of 3 Hz or less. It has the most significant amplitude and moves the slowest.

Theta: It has a frequency range of 3.5 to 7.5 Hz and therefore is considered a "slow" activity. It is natural in youngsters under the age of 13 and while sleeping, but abnormal in conscious adults.

Alpha: It does have a frequency range of 7.5 to 13 Hz. Is typically found in the posterior portions of the skull. It appears when you close your eyes and rest, and it disappears when you open your eyes or are alerted by any method (thinking, calculating).

Beta activity is defined as "quick." It also has a frequency of 14 Hz or higher. Whenever the human brain is busy and focused, beta waves occur. The presence of higher beta waves inside the forebrain can imply emotional valence.

2.Methodology

1) Software Methodology

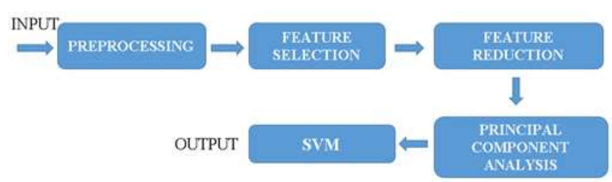

Figure 2: Block Diagram of Software Methodology

A) Preprocessing

The 'preprocess' function filters data to a frequency range of 0 to 75 Hertz. It generates new matrices with a sampling frequency of 200Hz and a frequency range of 0 to 75Hz. We employed a 'Low pass filter' with Finite Impulse Response. Bandpass was avoided since it would cause the EEG data to become unstable after processing.

B) Feature Extraction

Using the wavelet filter banks technique, we separate the

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electroencephalography pre-processed inputs into 5 frequencies sub-band. A filter at the lowest level divides the frequency range in half and produces high pass and low pass results (approximation coefficient).We then run the approximation coefficient through the filter. This is continued until the target bandwidths are not met. The procedure is repeated for each channel. We iterated for 62 channels in each iteration.

C) Feature Reduction

PCA is very much an eigenvector-based statistic method that uses singular value decomposition to transform a set of correlated training data into mutually statistically independent training features, known as principal components or PCs.

Principal Components Analysis Procedure:(1)Mean Normalization of feature (2) Creating a Covariance Matrix (3) Determining the Eigen Vectors (4) Obtain the minimized features or primary components.

D) Support Vector Machine

SVM is a common Supervised Learning method.SVM selects the highest points/vectors that aid in the creation of the hyperplane. These extreme examples are referred to it as support vectors, and also the method is known as the Support Vector Machine.

2) FPGA Implementation

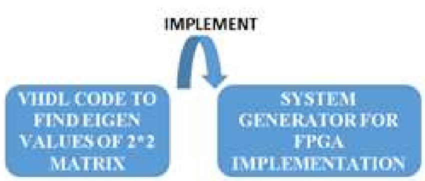


Figure 3: Methodology for FPGA Implementation

A VHDL code, as well as the testbench, was written to compute the Eigen Vectors of a 2*2 matrix using the CORDIC square root value algorithm. A Simulink model was created and the VHDL code was dumped into the black box to get the results for the Eigen Vector calculation and a hardware block was generated for the same.

3.Results and Discussions

The Results obtained in the Jupyter notebook is depicted in Figure 4 & Figure 5:

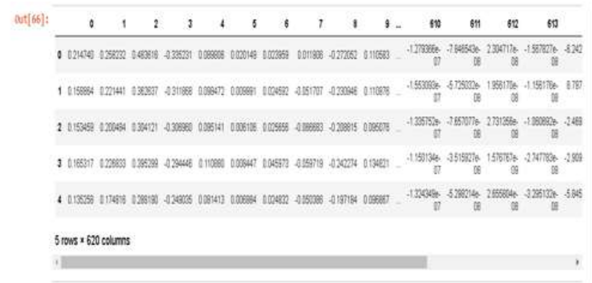
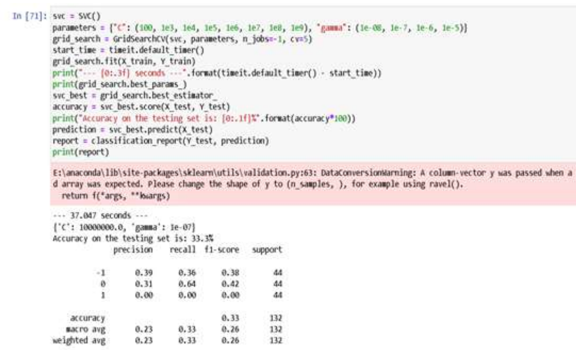


Figure 4: The Principal Component Analysis output



```
In [71]: svc = SVC()
parameters = {"C": (100, 1e3, 1e4, 1e5, 1e6, 1e7, 1e8, 1e9), "gamma": (1e-08, 1e-7, 1e-6, 1e-5)}
grid_search = GridSearchCV(svc, parameters, n_jobs=-1, cv=5)
start_time = timeit.default_timer()
grid_search.fit(X_train, Y_train)
print("--- {0:.3f} seconds ---".format(timeit.default_timer() - start_time))
print(grid_search.best_params_)
svc_best = grid_search.best_estimator_
accuracy = svc_best.score(X_test, Y_test)
print("Accuracy on the testing set is: {0:.1f}%".format(accuracy*100))
prediction = svc_best.predict(X_test)
report = classification_report(Y_test, prediction)
print(report)

E:\anaconda\lib\site-packages\sklearn\utils\validation.py:63: DataConversionWarning: A column-vector y was passed when a 1d array was expected. Please change the shape of y to (n_samples, ), for example using ravel().
  return f(*args, **kwargs)

--- 37.047 seconds ---
{'C': 10000000.0, 'gamma': 1e-07}
Accuracy on the testing set is: 33.3%
              precision    recall  f1-score   support

          -1       0.39      0.36      0.38        44
           0       0.31      0.64      0.42        44
           1       0.00      0.00      0.00        44

    accuracy                           0.33       132
   macro avg       0.23      0.33      0.26       132
weighted avg       0.23      0.33      0.26       132
```

Figure 5: The Support Vector Machine Output

The Results obtained in Xilinx14.5 are depicted in Figure 6, Figure 7, Figure 8 & Table 1:

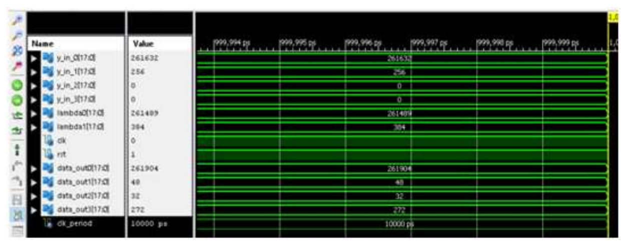


Figure 6: Simulation Waveform of Eigen Vector Calculation

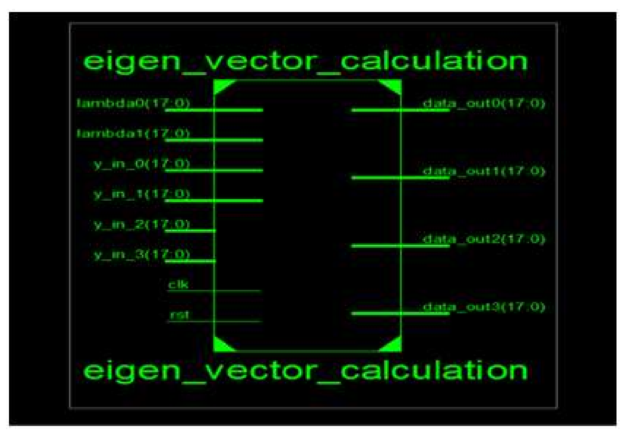


Figure 7: Schematic of Eigen Vector Calculation

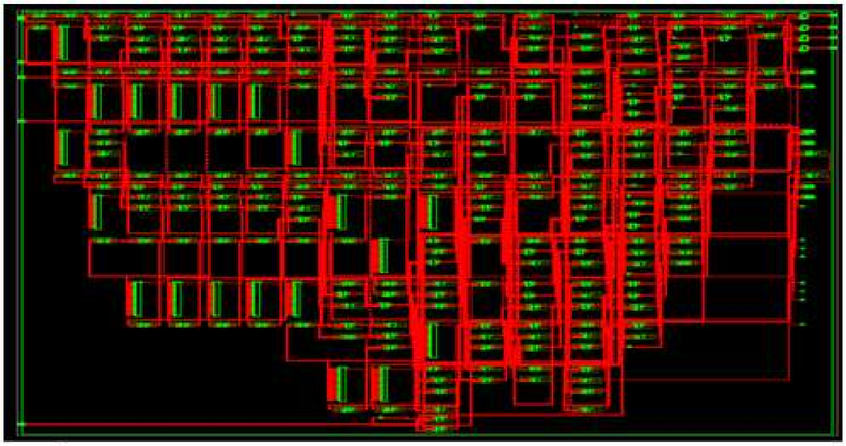


Figure 8: RTL Schematic

Table 1: Device Utilization Summary

Device Utilization Summary (estimated values)			
Logic Utilization	**Used**	**Available**	**Utilization**
Number of Slice LUTs	5070	27288	18%
Number of fully used LUT-FF pairs	0	5070	0%
Number of bonded IOBs	146	218	66%
Number of BUFG/BUFGCTRL/BUFHCEs	1	16	6%
Number of DSP48A1s	22	58	37%

The results obtained on a System generator for Eigen Vector Calculation are depicted in Figure 9 & Figure 10:

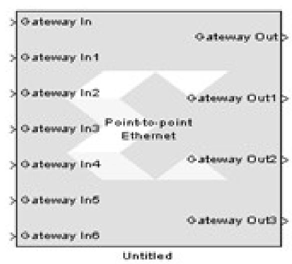


Figure 9: Hardware model generated in Simulink

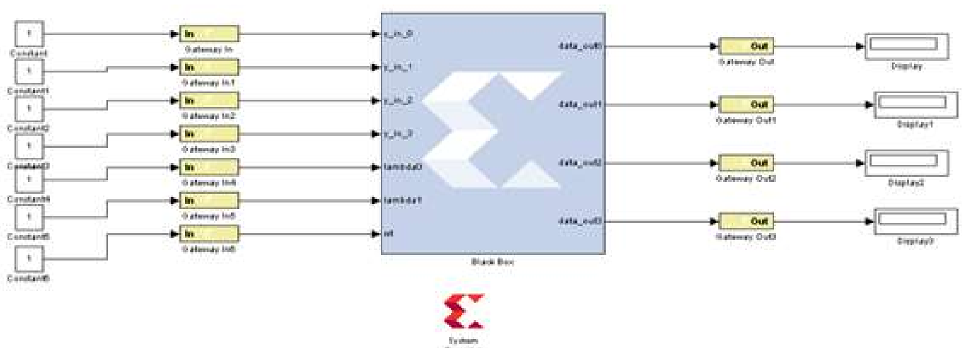


Figure 10: Simulink Model for Eigen Vector Calculation

4.Advantages

1. Emotion recognition has already been utilized in learning institutions since it helps to prevent violence.
2. HR assistants, some firms deploy AI with emotion detection API skills and the algorithm aids in identifying whether a candidate is sincere and genuinely interested in the position by analyzing intonations, and facial expressions.
3. Nowadays, face expression detection is being used extensively in the healthcare industry. They are using it to determine if a victim needs medication or to help physicians decide who to see first.

5.Applications

1. Focuses on analyzing a driver's performance during a race.
2. Emotion recognition is used in hospital environments to encourage relaxation and stress reduction.
3. Emotion recognition can be used for website optimization, with the system designed to obtain data on which advertisements draw the most attention, allowing appropriate material to be catered to audience demographics.

6.Conclusion

The 'preprocess' function filters data to a frequency range of 0 to 75 Hertz. It produces a unique matrix with a sampling frequency of 200Hz as well as a frequency range of 0 to 75Hz. Eventually, feature extraction is finished, for each EEG preprocessed data yielding 620 features. We apply Principal Component Analysis, or PCA, throughout the feature reduction step. The principal component analysis is an eigenvector-based statistic method that uses singular value decomposition to turn a set of correlated data into independently uncorrelated training features or PCs. Steps to Implement Principal Component analysis (PCA Analysis (1) Feature Mean Normalization (2) Covariance Matrix (3) Determine the Eigen Vectors (4) Determine the simplified features or major components The previous step's PCs will be passed further into the SVM classifier as output. A VHDL code & testbench for a 2*2 matrix was written and the waveform, RTL schematic was obtained on Xilinx 14.5. For the FPGA implementation, the Simulink Model was designed and the eigenvalues were computed using a system generator.

7.Future Scope

The approach applies to a wide range of signal processing and artificial intelligence applications. For improved performance, the PCA design can be used with various compressing and dimensionality reduction algorithms. It can also be used for real-time applications.

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