Recognition of valence using QRS complex in children with Autism Spectrum Disorder (ASD)

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Abstract. In children with a diagnosis of autism spectrum disorder (ASD), the absence of emotional inexpressiveness continues to be a consistent issue. This causes them to an unexpected emotional outbursts and meltdowns. This study utilizes the QRS complex derived from the Electrocardiogram (ECG) signals to investigate the positive (“Like”) and negative (“Dislike”) valence using a personalized emotion elicitation protocol using audio- and audio-visual cues in children who have ASD under the ages between 5 and 11 years. The sample size consisted of 15 controls and 15 children who have ASD. The acquired raw ECG signals are cleaned using various digital filters and the useful valence specific features are extracted from the QRS complex and are classified using the K nearest neighbour (KNN) and Ensemble learner. The control children were able to exhibit largely to the valence states, in contrast the children who have ASD did not show much difference in their valence states which was also verified using the Ensemble learner which achieved a maximum mean accuracy of 75.5% in controls and 70.5% in children who have ASD.

Keywords: - Autism Spectrum Disorder, Electrocardiogram, QRS complex, KNN, Ensemble classifier

1. Introduction

Autism Spectrum Disorder (ASD) is globally prevalent and as per the first epidemiologic studies conducted in early 1960s and 1970s in Europe and United States, there is a 20 to 30-fold increase in persons with ASD. In the United States of America, In the latest survey conducted by the Centre for Disease Control and Prediction (CDC) in 2018, 1 out of 59 children (1 among 37 boys and 1 among 151 girls) were reported with ASD. In India, about 2.3 Million children are identified with ASD[1]. ASD is a kind of neurological disorder that affects the functions of the brain and is anticipated in children under 3 years of age during the early stages of development[2]. Children who have ASD suffer from multiple sensory disorders, social function disability, language development delay, speech deficit, gastrointestinal issues, sleep disturbance, cognitive irresponsiveness, echolalia, and repetitive behaviour[3]. These impairments make them feel depressed and unable to communicate to others their thoughts or emotions. The inability towards this inexpressiveness push them to behave aggressively, go through a spontaneous emotional outburst or meltdowns[4]. Earlier studies on the emotion recognition system were based on the behavioural measures such as facial expression, gestures and speech for control children and adults[5–7]. These approaches are inaccurate and are not ideally suited for the
persons who conceal their emotions socially. Hence the physiological signals-based emotion recognition system paved way to unveil the masked emotions, also, used in Central Bureau of Investigation in lie detection[8], detection of stress in drivers due to prolonged driving[9], loneliness in old aged people and also in new-born child and in persons with ASD who cannot express their feelings. Physiological signals such as ECG, Electroencephalogram (EEG), galvanic skin response (GSR), Electrodermal activity (EDA), Respiration, skin temperature (SKT), Blood Volume Pulse (BVP), Phonocardiogram (PCG) etc are used by various researchers to detect the emotional states[10] and stress[11] in controls whereas only few studies are reported in children who have ASD. This work focuses specifically on the identification of valence states (Positive and Negative) using the QRS complex derived from ECG signals in special children. The QRS signal contains the information reading the pattern of the activation pulse and its direction of conduction which helps in emotion recognition[12].

2. Methodology

Figure 1 displays the valence recognition system ‘s work flow diagram as separate blocks, including various phases beginning with the collection of ECG data, removal of interferences from the raw ECG signals, data modelling, and pattern recognition using the KNN and Ensemble classifier.

![Figure 1. Valence recognition system Using QRS complex](image)

2.1. ECG Data Acquisition

The valence-based raw ECG signal was acquired from 15 controls and in 15 children aged 5 to 11 years with ASD . This study includes children with mild and moderate level of autism severity who were evaluated by the psychologists under several domains such as impairment in social interaction, communication and language delay, repetitive behaviour, emotional responsiveness using the Indian Scale for Assessment of Autism (ISAA) whose score ranged between 70 to 150. For each child who had ASD, a customised valence-inducing protocol was developed using their favourite and unfavourite audio- and audio-visual stimuli taken from internet sources. The cues were presented to them sequentially on a TV screen with an inbuilt speaker and the ECG signals were picked up by a small portable, wearable Heart Wear device and streamed using Bluetooth technology, simultaneously parents were given a set of questionnaires to rate the emotions felt by their child under 5-point scale.

2.2. Denoising of Raw ECG signal

The raw ECG signals were prone to various noises which is mainly introduced into the signal by the movement of the children, breathing, muscle artefacts, baseline wander, external sources such as powerline interferences. These interferences affect the useful morphological information of ECG that makes it difficult for interpretation by the doctor. In this work the baseline wander is eliminated by subtracting the 8th level of decomposed signal using the Daubechies db4 mother wavelet from the corrupted ECG signal[13] and other high frequency noises are removed using the 6th order low pass Butterworth filter by using a higher cut-off frequency of 45 Hz. Using the well-known Pan-Tompkins algorithm, the QRS complex is extracted from the ECG signal [14].
2.3. Feature Extraction and Classification

The QRS signal are extracted for its useful valence specific linear and nonlinear features such as 18 statistical features namely Mean, Median, Standard Deviation, Mean Absolute value of First difference of raw signal(Mean I), Mean Absolute value of First difference of raw signal(Mean I), Mean Absolute value of First difference of Normalized signal (Mean II), Mean Absolute value of Second difference of raw signal(Mean III), Mean Absolute value of Second difference of Normalized signal(Mean IV)[15], First quartile (Q1), Second Quartile (Q2), Third Quartile (Q3), Interquartile range(IQR)[16], Harmonic Mean, Nan Mean, Mode, Minimum, Maximum, Variance, higher order statistical features such as Skewness and Kurtosis, 4 Nonlinear features like Entropy, Hurst[12], Sample Entropy (SampEn), Approximate Entropy(APEN)[17]. All the features that were extracted were statistically analysed using the one-way ANOVA using SPSS tool. The features that showed more significance towards the two valence states, whose p-values were less than 0.05 are selected for feature classification using the KNN and Ensemble algorithms. The classification is done using the holdout validation of 70 percent and 30 percent of datasets for training and testing respectively. The accuracy of the predicted class is calculated using the confusion matrix obtained from the two classifiers.

3. Results

3.1. Pre-Processing

To remove the unwanted low and high frequency noises from the signal, the acquired raw ECG signals were denoised. By subtracting the 8th level of decomposition from the using the DWT Daubechies db4 as the mother wavelet, the baseline wander free ECG signal was obtained. The removal of high frequency noises which also includes the PLI was done using the Low Pass 6th order Butterworth filter. The QRS complex from the ECG signal is derived using the Pan-Tompkins algorithm is shown in Figure 2.

![Figure 2. Derivation of QRS complex using Pan Tompkins algorithm](image-url)
3.2. Classification of QRS complex in to Valence states

The QRS complex in considered as one of the most important fiducial point in ECG which helps in diagnosis of various cardiac diseases as well as in determining the emotional state of an individual. The statistical analysis of one-way ANOVA tabulated in Table 1 shows that the valence attributes from QRS complex such as Standard Deviation, Mean I, Mean III and Mean IV of the statistical features were found to show more significance for the two valence states in the controls were as Mean, Median, Q1, Q2, Q3, Harmonic Mena, Trimean, Nan mean, Mode and Minimum feature were found to be more significant for the children who have ASD. The HOS feature Kurtosis and nonlinear feature entropy was found to be more significant in the case of controls.

| Emotional Features | p-value |                 |                  |
|-------------------|---------|-----------------|-----------------|
|                   |         | Controls        | ASD             |
| Mean              | 0.956   | 0.038           |
| Median            | 0.454   | 0.050           |
| Standard Deviation| 0.000   | 0.364           |
| Mean I            | 0.000   | 0.576           |
| Mean II           | 0.502   | 0.907           |
| Mean III          | 0.000   | 0.908           |
| Mean IV           | 0.032   | 0.787           |
| Q1                | 0.702   | 0.042           |
| Q2                | 0.404   | 0.050           |
| Q3                | 0.311   | 0.048           |
| IQR               | 0.000   | 0.921           |
| Harmonic mean     | 0.914   | 0.040           |
| Trim mean         | 0.566   | 0.045           |
| Nan mean          | 0.596   | 0.038           |
| Mode              | 0.284   | 0.025           |
| Max               | 0.577   | 0.237           |
| Min               | 0.284   | 0.025           |
| Variance          | 0.001   | 0.722           |
| Skewness          | 0.081   | 0.102           |
| Kurtosis          | 0.001   | 0.345           |
| Entropy           | 0.007   | 0.909           |
| Hurst             | 0.095   | 0.240           |
| SampEn            | 0.977   | 0.572           |
| APEN              | 0.115   | 0.787           |

The useful valence information from the derived QRS complex from both the population were classified using the KNN and Ensemble classifier with a holdout validation of 70 % data for training the classifiers and the remaining 30 % of the dataset for the testing purpose and the accuracy of the predicted class is found from the confusion matrix of the two class Positive(“Like”) and Negative (“Dislike”) as shown in Table 2. It is inferred from the results that the first quartile Q1 feature of the QRS complex were able to differentiate between the two valence states effectively and resulted in a maximum accuracy on average of 73.5% in control and 73% in children who have ASD respectively with the help of KNN classifier. While combining the selected features the accuracy was found to be improved by achieving
a maximum accuracy on average of 75.5% and 70.5% in control and children who have ASD using Ensemble classifier. The fusion of the most significant features captures the valence information and has an improved accuracy in both the population.

**Table 2.** Classification of Time domain features (statistical, HOS and Nonlinear) of QRS using KNN and Ensemble classifiers

| Emotional Features | Classifiers | Controls Positive valence % | Controls Negative valence % | Controls Average % | Children who have ASD Positive valence % | Children who have ASD Negative Valence % | Children who have ASD Average % |
|--------------------|-------------|-----------------------------|-----------------------------|-------------------|------------------------------------------|----------------------------------------|----------------------------------|
| All significant     | KNN         | 64                          | 79                          | 71.5              | 59                                       | 70                                     | 64.5                             |
|                     | Ensemble    | 73                          | 78                          | **75.5**          | **69**                                   | 72                                     | **70.5**                         |
| Mean                | KNN         | 62                          | 74                          | 68                | 63                                       | 70                                     | 66.5                             |
|                     | Ensemble    | 62                          | 74                          | 68                | 64                                       | 67                                     | 65.5                             |
| Median              | KNN         | 59                          | 71                          | 65                | 65                                       | 72                                     | 68.5                             |
|                     | Ensemble    | 60                          | 71                          | **65.5**          | 66                                       | 70                                     | 68                               |
| Standard Deviation  | KNN         | 70                          | 74                          | 72                | 60                                       | 67                                     | 63.5                             |
|                     | Ensemble    | 69                          | 75                          | 72                | 60                                       | 67                                     | 63.5                             |
| Mean I              | KNN         | 60                          | 74                          | 67                | 60                                       | 71                                     | 65.5                             |
|                     | Ensemble    | 58                          | 76                          | 67                | 61                                       | 70                                     | 65.5                             |
| Mean III            | KNN         | 69                          | 68                          | **68.5**          | 65                                       | 68                                     | 66.5                             |
|                     | Ensemble    | 69                          | 68                          | **68.5**          | 65                                       | 68                                     | 66.5                             |
| Mean IV             | KNN         | 63                          | 77                          | 70                | 58                                       | 79                                     | 68.5                             |
|                     | Ensemble    | 63                          | 77                          | 70                | 61                                       | 74                                     | 67.5                             |
| Q1                  | KNN         | **65**                      | **82**                      | **73.5**          | **69**                                   | **77**                                 | **73**                           |
|                     | Ensemble    | 65                          | 80                          | 72.5              | 70                                       | 74                                     | 72                               |
| Q2                  | KNN         | 59                          | 71                          | 65                | 65                                       | 72                                     | 68.5                             |
|                     | Ensemble    | 60                          | 71                          | **65.5**          | 66                                       | 70                                     | 68                               |
| Q3                  | KNN         | 69                          | 73                          | 71                | 68                                       | 69                                     | 68.5                             |
|                     | Ensemble    | 69                          | 73                          | 71                | 69                                       | 68                                     | 68.5                             |
| IQR                 | KNN         | 75                          | 70                          | **72.5**          | 50                                       | 68                                     | 59                               |
|                     | Ensemble    | 75                          | 70                          | **72.5**          | 54                                       | 70                                     | 62                               |
| HM                  | KNN         | 60                          | 79                          | 69.5              | 60                                       | 71                                     | 65.5                             |
|                     | Ensemble    | 61                          | 77                          | 69                | 60                                       | 71                                     | 65.5                             |
| TM                  | KNN         | 66                          | 76                          | 71                | 54                                       | 66                                     | 60                               |
|                     | Ensemble    | 67                          | 76                          | **71.5**          | 54                                       | 66                                     | 60                               |
| Nan Mean            | KNN         | 62                          | 74                          | 68                | 63                                       | 70                                     | 66.5                             |
|                     | Ensemble    | 62                          | 74                          | 68                | 64                                       | 67                                     | 65.5                             |
| Mode                | KNN         | 64                          | 80                          | 72                | 58                                       | 73                                     | 65.5                             |
|                     | Ensemble    | 65                          | 79                          | 72                | 60                                       | 69                                     | 64.5                             |
| Min                 | KNN         | 64                          | 80                          | 72                | 58                                       | 73                                     | 65.5                             |
|                     | Ensemble    | 65                          | 75                          | 70                | 60                                       | 69                                     | 64.5                             |
| Variance            | KNN         | 70                          | 74                          | 72                | 60                                       | 67                                     | 63.5                             |
|                     | Ensemble    | 69                          | 76                          | **72.5**          | 61                                       | 67                                     | 64                               |
| Kurtosis            | KNN         | 62                          | 72                          | 67                | 55                                       | 70                                     | 62.5                             |
|                     | Ensemble    | 62                          | 72                          | 67                | 58                                       | 68                                     | 63                               |
| Entropy             | KNN         | 63                          | 71                          | 67                | 62                                       | 70                                     | 66                               |
|                     | Ensemble    | 61                          | 74                          | **67.5**          | 60                                       | 70                                     | 65                               |
The overall performance of the KNN and Ensemble classifiers is shown in Figure 3 shows that Ensemble learner achieved the maximum average accuracy of 75.5% and 70.5% in controls and children who have ASD respectively.

![Figure 3](image)

**Figure 3** Classification Accuracy of Valence states using KNN and Ensemble Classifier

4. **Conclusion**

In this study, the QRS complex derived from ECG signal was used for investigating the positive and negative valence in children who have ASD and controls. Learning the internal states in children with ASD using ECG signals allows us to devise a system that automatically detects the transition of emotions and notifies the parents or caregivers before the occurrence of sudden emotional upsurge in these special children. The acquired raw ECG signals were cleaned using the DWT Daubechies db4 as the mother wavelet and low pass 6th order Butterworth filter and the all the statistical time domain and nonlinear features that are extracted were classified using the KNN and Ensemble classifier and has achieved an overall maximum mean accuracy of 75.5% in controls and 70.5% in children who have ASD using Ensemble algorithm.

5. **References**

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