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Screening Children with Autism by Developing Smart Toy Cars

Ehsan Sadeghipoor[1*], Manoochehr Moradisabzevar[2]
[1]*M.S. in Mechatronics Engineering, Mechatronic Engineering Department, Tehran University, Iran*
[2]*Assistant Professor, Computers and Electrical Engineering Department, Tehran University, Iran*

Abstract– *Autistic spectrum disorders are categorized under developmental disorders and lead into a wide range of symptoms in the patients. They are referred to as autism spectrum, since the intensity and the extent of their symptoms vary person to person based on disorder's intensity. In this study, a smart toy car was developed for screening children with autism. In making the toy car, field-programmable gate array was exploited which is an integrated circuit capable of high-speed planning. Appropriate selected features were the ones that identified repetitive and stereotypical motions in movement, which are normally comprised of 9 features. Finally, in the most appropriate conditions, the classification of aforementioned features was carried out using support vector machine algorithm with polynomial kernel with an order of 5. Autistic children screening was carried out with an accuracy of 100%*

Keywords:*FGPA, spatio-temporal data, autism screening, smart toys, SVM*

I. Introduction

Leo Kanner was the first to describe autism in 1943. Autistic spectrum disorders (ASDs) are a clinical diagnosis characterized by impaired social interaction, restricted interests, and repetitive behaviors.

They are categorized as developmental disorders that lead into a wide range of symptoms in the patients. Since the intensity and extent of the symptoms vary person to person based on the intensity of the disorder, these disorders are called autistic spectrum disorders. Their common symptoms are difficulty in having social interaction, verbal communication, and eye contact. Patients with autism tend to engage in repetitive and stereotypical actions, such as moving the head back and forth, stereotypical finger movements, or moving an object back and forth. While many such children seem to be healthy and may not be diagnosed with autism until school age, others may be diagnosed at an early age due to intense autistic behaviors. ASDs are more widespread in developed countries. It is reported that 6.5 out of 1000 Americans suffer from ASDs. This significant increase is mostly associated with changes in diagnostic approaches, rather than an actual biological increase. Autism symptoms may emerge after months or even years of fairly natural development. In one fourth of cases, parents reported that their children first uttered meaningful words, but were later verbally impaired. In fact, the core symptom of autism is impaired social communication. Healthy children are significantly sociable from first weeks after being born. In fact, human children are inherently prepared for social interaction and human face recognition. Autistic children, however, show a lower tendency to human face, have little eye contact, and rarely show social behaviors, such as pointing at things, showing interest in other children, and talking. Since many motion detectors have emerged in recent years that are capable of transmitting information regarding the movement of every moving thing, a large amount of such spatio-temporal data are available. Therefore, if analyzed properly, such data can provide us with valuable information in various fields, such as moving objects behavior or the type of a moving object [1]. Due to the importance of this issue, valuable information was obtained by analyzing and identifying patterns in such data, especially motion data of the objects that move in a limited space, such as a room. These pieces of information can be useful in medical applications, especially in diagnosing diseases that lead into movement disorder, such as Parkinson's disease and autism. Therefore, by designing and implementing an automatic detector of repetitive or specific patterns, autistic children could be diagnosed to some extent with the least physician intervention. Since children spend a long time playing with toys when they are about 6, this study aimed at tracing children's behavior while playing with different toys and collecting data using appropriate detectors implemented in toys. Finally, data obtained from toys were analyzed.

II. Literature review

Many studies have been carried out regarding movement analysis, repetitive movements in particular, some of which are presented here. For treating children with autism, a robot was made by B. Vanderborght et al. in [1]. The robots taught children some social skills in the form of storytelling. The reason why robots were used in the study was that autistic children felt more comfortable communicating with them, rather than humans. In order to strengthen this point, their hardware was soft so that children could hug them and had green eyes which made them peaceful. D. Oller et al. in [2] diagnosed patients with autism using audio parameters. They recognized children with verbal delay from the ones with normal development. The problem in carrying out this project was that children's voice was recorded in a real environment and the background noises were removed using a completely automatic method. Then, the appropriate extracted features were analyzed. Recording the voices of three categories of children was started from 2006. On the whole, the voices of 232 children were recorded in a period of 1486 days. In order to measure and compare data, 12 features were extracted which were categorized into four groups. The presence or absence was given a value of 0 or 1. Finally, their occurrence rates were exploited. In [3], P. Perego et al. diagnosed autism through analyzing upper limb movements using support vector machine (SVM) separation methods. In order to achieve this, children's movements in holding and dropping items were exploited. These movements are highly significant in children's development and if a child is not capable of doing it, he/she can not do more complex movements. An experiment was devised to confirm this hypothesis, in which 10 preschool children with autism and 10 preschool children as control group were asked to perform a task. In this way, an accuracy rate of 100% was achieved using soft margin algorithm, and with some rigidity the accuracy rate was calculated to be 92%. P. Bjorne et al. used a computing model for simulating attention in [4] which was comprised of three layers. It distinguished between children with autistic spectrum from normal children. Its three layers were reinforcement learning, processing, and automation layers. The aim was to develop a model to make developmental disorders diagnosis more efficient. Therefore, this model could be used to show normal and abnormal development, such as autistic people's development. In [5], C. Liu et al. diagnosed autism using physiological responses. Using machine learning, a model was developed from autistic children based on their physiological responses. In [6], A. Kannappan et al. exploited a fuzzy cognitive map (FCM) for predicting and diagnosing autistic spectrum disorder. FCMs can model complex systems' behavior and are exploited in developing knowledge-based systems. They combine the advantages of fuzzy logic and neural networks. In order to overcome the limitations of FCM, a non-supervised learning method was exploited. Finally, a decision making system with FCM was exploited which was based on human knowledge. It was trained by Heb-biannon-linear learning algorithm and predicted autism. In [7], A. Stoit et al. analyzed the weak points in colleague or playmate modeling in autistic people. In order to achieve this, some people with autism were asked to take part in a computer game that balanced a table and a ball. They played the game in both single-player and two-player modes. Results showed that they failed to predict the other player's behavior. While they had problems in two-player mode, they performed well in single-player mode, in which they raised the ball using the table alone. In [8], C. Min et al. aimed at proposing quantitative criteria for social responses in autism diagnosis. A robot was used in carrying out the diagnosis which was comprised of various parts. Each part was used for analyzing an autistic symptom. Common characteristics of the studies regarding motion analysis are that all of them were carried out in a large scale and used position sensors, such as GPS. Therefore, they are not appropriate for small places, such a house, because some sensors, such as GPS are not precise enough for small places in the first place. Second, using a position sensor with a desirable precision is costly. Moreover, the studies carried out in this regard required experimental conditions for diagnosing autism and could not be carried out at home. On the other hand, one of the problems in diagnosing autism is late referral to autism diagnosis centers. Therefore, those methods are not helpful in early diagnosis of autism. Due to this reason, we aimed to screen children in uncontrolled situations while engaged in routine activities, an important instance of which is playing. Then, they were referred to physicians if needed.

III. Diagnostic tests

Diagnosing autism is neither simple nor certain. No blood test, imaging, or clinical examination can detect this disorder. Its only way is to observe retrospectively the individual's development, behavioral development, and communication and verbal skills overtime. Therefore, a child suspected of having autism should be examined by a neurologist, psychologist, behaviorist, and speech therapist. May be it is due to this reason that although autistic symptoms start from 7 to 8 months old, it is diagnosed between 2 to 3 years old. Autism specialists believe that for a better prognosis of a child, diagnosis under the age of 3 is crucially important. The outbreak of autistic spectrum disorders is recently increasing. Since autistic patients are dependent on their families throughout their whole life and need special attention, an early diagnosis of autism in children is highly important in treatment. In developing countries, however, its diagnosis is delayed by several years due to a variety of reasons, including unawareness, neglecting or even denying the symptoms of autism on the part of parents, and lack of specialists. On the other hand, diagnosing and screening autism requires the presence of specialists or providing controlled experimental conditions. Therefore, these methods are not quite common in societies, developing countries in particular. Hence, this study aimed at proposing a method for an automatic diagnosis and screening of this disorder using computer and smart algorithms. It raises parents awareness regarding their children's probable problem and makes the early diagnosis of autism and consequently its more effective treatment possible.

IV. Support vector machine algorithm

SVM is a method for classifying linear and non-linear data. It is a supervised learning algorithms that is used in regression and classification. Its classifier works based on linear classification. In this method, a non-linear map is exploited for converting the original plane to a high-dimensional plane. Then, it finds the best hyperplane classifier in the new dimension. The new hyperplane is comprised of a decision border that separates records belonging to different classes from one another. In a linear division of data the end is to select a line with the highest margin. Quadric programming (QP) was exploited for solving optimal line equation. QP is a well-known method in solving problems with limitations. First, φ functions mapped highly-complex data to a higher-dimension space so that the SVM can classify highly-complex data. Eq. (3) is the hyperplane equation for classifying data. Eq. (2) and Eq. (3) are parallel planes equations based on maximum margin. If both functions are plotted, the distance between two margin

planes will be $\frac{2}{\|w\|}$.

$$w \times x - b = 0 \qquad (1)$$

$$w \times x - b = -1 \qquad (2)$$

$$w \times x - b = 1 \qquad (3)$$

where*x* is the input variable, *w* is the normal vector of separating line, and *b* is the intercept of the separating line. For the sake of simplicity, a linear function was used in calculations.

V. Methodology

When a child held the toy car in his/her hand and moved it, a string of momentary accelerations were produced. As shown in Fig. (1), repetitive movements were divided into 4 groups, including circular, linear back and forth, semi-circular, and sinusoidal movements, while non-repetitive movements were classified under another category. The only important issue is the repetitive or non-repetitive nature of movements and the form of the movement was not important. Since the cost of human resource for creating appropriate testing conditions was high, momentary acceleration storing system had to be reliable enough, because it saved the trouble of redoing all the operation due to system failure. Hence, collecting data from children's play was not carried out first. By analyzing preliminary data with respect to the information obtained related to autism, appropriate feature extraction became possible. Then, collecting real information was carried out. Testing autistic children was carried out in affiliation to the Center for the Treatment of Autistic Disorders (CTAD). The autistic children were asked to play with toy cars in a room around 3 meters in 3 meters. No other person was in the room, except for the examiner.

Collecting information from children without autism was carried out in a preschool in Kooy-e Niayesh, Bandar Abbas, Iran. They also played with toy cars in a room around 3 meters in 3 meters. No other person was in the room, except for the examiner. Children were allowed to play with the toys as much as they wished. Some children played with toy cars for approximately 15 minutes, while some other were not willing to play with them and spent a short time with them. The information obtained from the latter was removed due to their lack of data. Table (1) shows an example of data obtained from tested children.

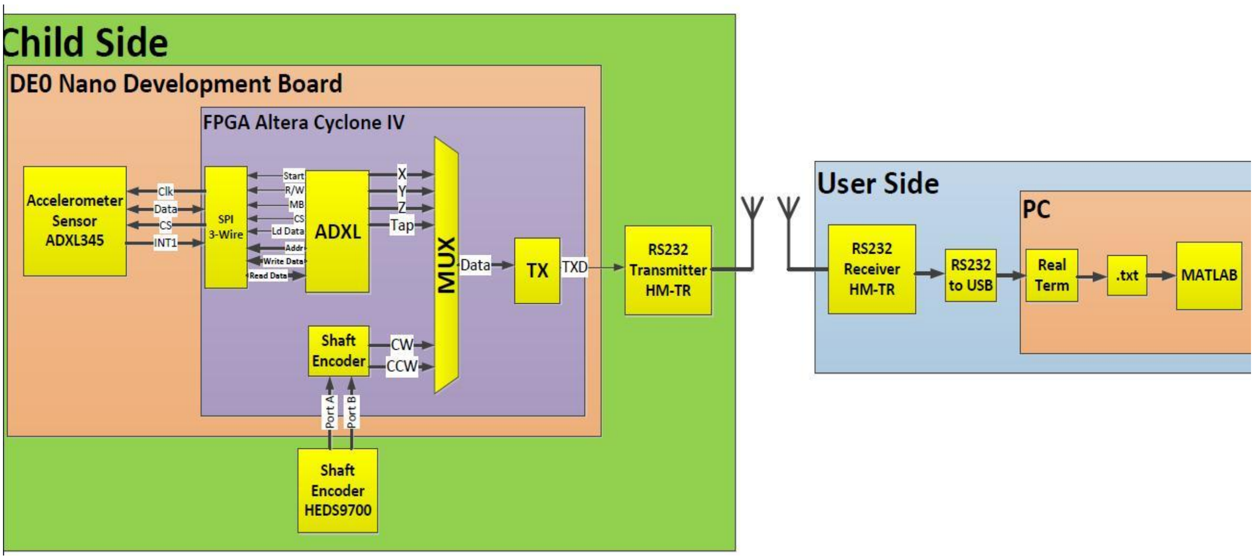


Table (1) shows an example of data obtained from tested children.

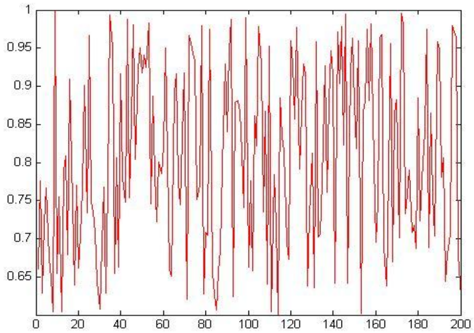
right rotation	left rotation	axis mean X	axis variance X	Skewness X	axis mean Y	axis variance Y	Skewness Y	axis mean Z	axis variance Z	Skewness Z	number of taps	class
220	285	0.32	0.32	-0.01	0.22	0.15	-0.08	0.33	1.24	-0.08	12	1
229	219	0.34	0.31	-0.03	0.20	0.15	0.08	0.34	1.21	0.05	11	1
276	248	0.32	0.32	0.17	0.21	0.18	-0.12	0.37	1.22	-0.11	8	1
247	134	0.12	-0.10	0.00	0.12	-0.10	0.00	0.12	0.80	0.02	5	0
317	167	0.24	0.31	-0.06	0.11	-0.10	0.10	0.12	0.80	-0.05	4	0
310	178	0.23	0.30	-0.02	0.11	-0.09	-0.09	0.11	0.79	0.14	2	0
174	57	0.24	0.30	-0.02	0.12	-0.09	-0.06	0.12	0.80	-0.05	5	0
228	105	0.22	0.30	0.03	0.11	-0.11	-0.01	0.12	0.80	0.02	2	0
330	124	0.24	0.30	-0.06	0.12	-0.10	0.02	0.12	0.80	0.04	2	0
401	246	0.23	0.31	-0.06	0.11	-0.09	-0.10	0.12	0.81	-0.07	0	0
341	154	0.23	0.28	0.15	0.11	-0.10	0.00	0.12	0.81	-0.06	6	0
277	109	0.23	0.27	0.11	0.12	-0.10	0.09	0.12	0.80	-0.04	5	0
470	273	0.23	0.32	-0.10	0.11	-0.10	-0.05	0.11	0.81	-0.13	1	0
254	133	0.23	0.28	0.17	0.12	-0.10	0.07	0.12	0.81	-0.10	8	0
191	279	0.33	0.35	-0.14	0.20	0.16	-0.09	0.35	1.22	-0.08	9	1
196	278	0.34	0.31	0.05	0.20	0.15	0.03	0.34	1.18	0.08	7	1

A frame of sent data is as follows from which data are extracted.

FF C5 CC 12 08 06 31 11 41 FF

“FF” separates information frames from one another. In other words, the bit strings between “FF ...FF” are the desired data. The length of each sent frame is 16 bits. The first and second bits are momentary acceleration values along *x* axis, the third and fourth bits are momentary acceleration values along *y* axis, the fifth and sixth bits are momentary acceleration values along *z* axis, the seventh and eighth bits are the number of taps on the car, the ninth, tenth, eleventh, and twelfth bits are the number of clockwise rotations, and the thirteenth, fourteenth, fifteenth, and sixteenth bits are the number of anti-clockwise rotations.Fig. (2) shows a general scheme of the project.

Fig. (2) General scheme of the project



Having extracted information from children's play with toy cars, some pieces of information which lacked data were removed, since they were not suitable for analysis. Finally, the number of data frames was equalized for all children. For each child, 200 frames were obtained. Data obtained from the toy cars were the number of left rotations, number of right rotations, momentary acceleration along *x, y,* and *z* axes, and the number of taps exerted on the car by children. Then, mean, variance, and skewness of each angle were extracted as other features, the overall number of which was 9. Fig. (3), Fig. (4), and Fig. (5) show acceleration means along *x, y,* and *z* axes for healthy children.

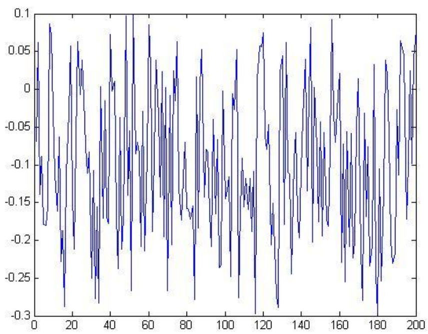


Fig. (3) Acceleration mean along *x* axis

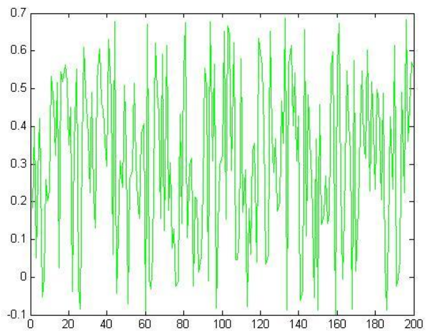


Fig. (4) Acceleration mean along *y* axis

Fig. (5) Acceleration mean along *z* axis

Fig. (6), (7), and (8) show acceleration means for children with autism along *x, y,* and *z* axes.

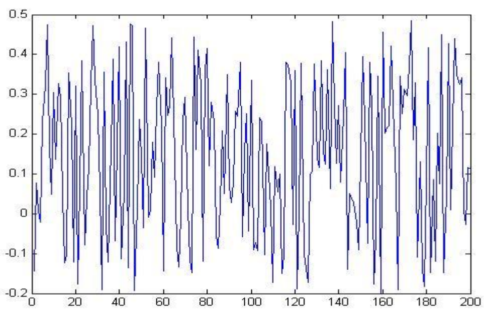


Fig. (6) Acceleration mean along *x* axis

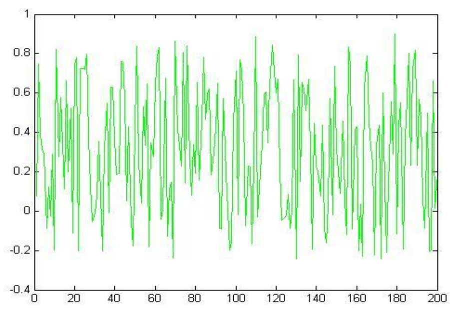


Fig. (7) Acceleration mean along *y* axis

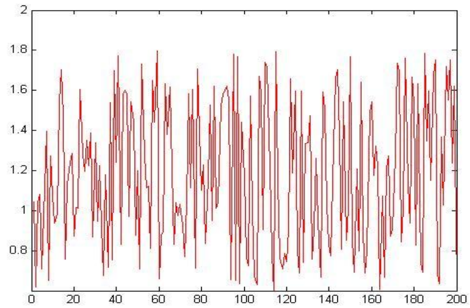


Fig. (8) Acceleration mean along *z* axis

5.1. Creating database

Since the main aim was an early diagnosis of autism in children with this disorder and distinguish from the children without autism, first a data collection method was devised to collect and store data required for later analysis. Various sensors could have been used for collecting information regarding movement, one of which was position sensor. These sensors, such as GPS, lack the precision required for the aim of the project. Another method was to use a camera recorder and identify the toy car in video recordings. Its shortcoming, however, was that it required experimental conditions and preliminary adjustments. Moreover, like position sensor, it could have been costly. Hence, an FPGA board was exploited which was equipped with momentary accelerometer capable of storing the measured data. The developer board used was DE0-Nano in which an ADX345 accelerometer was implemented. HM-TR RS232 wireless module was also used for transmitting data to a computer. Since the aim was to find and identify repetitive and stereotypical movements, calculating the mean and variance of momentary acceleration during movement were useful. Since a repetitive movements have a limited range of momentary acceleration, it is expected that they have a lower variance, compared to random movements. Table (2) shows the selected features for identifying various patterns in autistic children's play.

Table (2) Preliminary extracted features

Feature name	Description	
Mean	Mean of all stored momentary accelerations during the whole playing period	μ_x, μ_y, μ_z
Variance	Variance of all stored momentary accelerations during the whole playing period along *x*, *y*, and *z* axes	$\delta_x^2, \delta_y^2, \delta_z^2$
Number of wheel rotations	Number of wheel clockwise and anti-clockwise rotations	N_{cw}, N_{ccw}
Number of taps	Number of pushing times during the whole playing period	N_j
Time	Time spent playing with a smart car	T

5.2. Separation using support vector machine

In order to classify the data obtained from patients and non-patients, data were classified into training set and testing set, so that 30% of the data were used for training and the rest were used for testing the SVM. The number of healthy children was 19, out of which 11 were selected based on the relatively enough number of participants. The number of children with autism was 12, out of which 5 were selected based on the relatively enough number of participants. Where children spent a short time playing or did not pay any attention to the smart cars, their data were not used.

Training data which used the radial basis function (RBF) kernel in Eq. (4) were fed to the SVM. Then, the SVM calculated kernel values based on training data. Finally, calculated values were tested using testing data. Results are shown as follows.

$$\text{RBF Kernel} = \boldsymbol{k}(\boldsymbol{x}, \boldsymbol{x}') = \mathbf{exp}\left(-\frac{\left\|x-x'\right\|^2}{2\sigma^2}\right) \quad (4)$$

Fig. (9) shows SVM results for 11 training data.

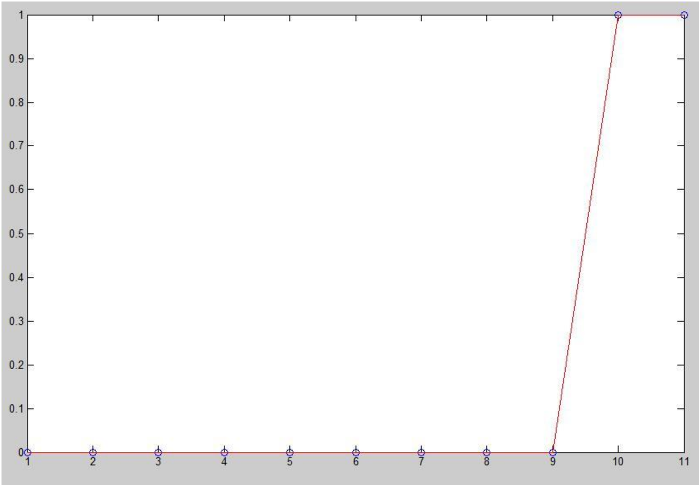


Fig. (9) SVM results for training data

The points marked with cross (+) was the class which could include autistic or non-autistic children, while circles show SVM output. As shown in Fig. (9), the SVM could accurately classify all testing data. Table (3) shows SVM output evaluation criteria.

Table (3) Criteria for evaluating SVM output

Accuracy	sensitivity	specificity	f_measure
1	1	1	1

The SVM could accurately classify testing data. It diagnosed 3 patients out of 11 subjects. Its accuracy is expected to be related to the appropriateness of extracted features.

VI. Conclusion

The aim of this study was to develop an SVM in diagnosing autistic children through identifying different and specific patterns in spatio-temporal data. Since autistic children tend to do repetitive and stereotypical tasks, this tendency also emerges in their playing with toy cars. The important factor was analyzing movement data of an object or person moving in a small space, such as a room. Therefore, using a sensor with desirable precision was crucially important in storing spatio-temporal data. In order to collect required data for testing the smart toy cars using the proposed method, momentary acceleration of the car along x, y, and z axes, number of clockwise and anti-clockwise wheel rotations, and the number of taps on the car were stored for autistic and non-autistic children during their play. Then, children were screened through analyzing toy car movements of both groups of children. Finally, using SVM classifier with polynomial kernel with the order of 5, data were classified and autistic children were screened with an accurate classification rate of 100%.

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