Original Article

Diagnosis of Autism in Children Based on their Gait Pattern and Movement Signs Using the Kinect Sensor

Abstract

Background: Autism spectrum disorders are a type of developmental disorder that primarily disrupt social interactions and communications. Autism has no treatment, but early diagnosis of it is crucial to reduce these effects. The incidence of autism is represented in repetitive patterns of children's motion. When walking, these children tighten their muscles and cannot control and maintain their body position. Autism is not only a mental health disorder but also a movement disorder. **Method:** This study aims to identify autistic children based on data recorded from their gait patterns using a Kinect sensor. The database used in this study comprises walking information, such as joint positions and angles between joints, of 50 autistic and 50 healthy children. Two groups of features were extracted from the Kinect data in this study. The first one was statistical features of joints' position and angles between joints. The second group was the features based on medical knowledge about autistic children's behaviors. Then, extracted features were evaluated through statistical tests, and optimal features were selected. Finally, these selected features were classified by naïve Bayes, support vector machine, k-nearest neighbors, and ensemble classifier. **Results:** The highest classification accuracy for medical knowledge-based features was 87% with 86% sensitivity and 88% specificity using an ensemble classifier; for statistical features, 84% of accuracy was obtained with 86% sensitivity and 82% specificity using naïve Bayes. **Conclusion:** The dimension of the resulted feature vector based on autistic children's medical knowledge was 16, with an accuracy of 87%, showing the superiority of these features compared to 42 statistical features.

Keywords: *Autism, classification, gait pattern, Kinect sensor, statistical features*

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Introduction

Autism is a spectrum disorder, and its symptoms vary from mild-to-severe levels in different individuals.[1] Autism can make it difficult for a person to communicate with others.[2] It can also lead to repetitive motions in the individual.[3] Some of its symptoms can be seen at 12 months old. While other children may develop normal language and social skills for a while, they regress with the onset of autism.[4] This process is called regressive autism.

Autistic children may be sensitive to touch, specific odors, loud noises, high temperatures, and even specific colors.[5-7] These people have particular tendencies, such as repetitive and limited tasks and behaviors, insistence on monotony, and inflexibility.[8] Several people with autism suffer from mental disabilities or speech disorders, such as slurred speech.[9-11] Besides these movements, there are abnormal walking patterns and other unusual movement signs, such as tiptoeing in people with autism.[12,13] Self-harm and risky behaviors in younger patients are common diseases of autism.[3,14]

Autism disorder can lead to changes in muscle use patterns, position control, and balance. Therefore, motor symptoms can be clinically important. The nerve glands and cerebellum of people with autism differ from healthy people.[15] Children with autism cannot walk like normal people and usually drag their feet on the ground, which causes muscle damage. Of course, this happens more when climbing the slope or facing an obstacle on the ground. The movement pattern of autistic is like individuals after stroke, which includes loss of stability and reduction of motion in the ankle joint.[16] Autistic children perform repetitive motions at the bottom of the trunk and are weak in keeping their balance.[17]

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There is no cure for autism, but early diagnosis of this disease can reduce the severity of the disease and make an autistic person to be independent. To develop autism, strategies such as behavioral therapy, speech therapy, music therapy, and focusing on helping the patient to interact with people and the surrounding environment should be applied.[18]

The diagnosis of autism disorder is usually based on the examination of behaviors, electroencephalography-signals, and brain magnetic resonance imaging.[19-21] In addition, the study of gait patterns and movement signs of people can be one of the autism diagnosis methods. Researchers are trying to develop automated diagnosis systems with minimal human intervention, faster screening, and easier availability.[22] An automatic diagnosis system based on a Kinect sensor is one of the potential methods of nonintervention diagnosis.[23] Several studies have been conducted using Kinect sensor for identification and investigation of autistic movement. These studies identify individuals with autism from healthy individuals using joint-coordinate data and analysis of the gait cycle.[24,25] According to these studies, the accuracy of the Kinect sensor for clinical use in detecting patients with autism is high.[26]

Research Challenge and Motivation

Considering that gait patterns and movement symptoms of autistic people differ from healthy people, the information about this process can be used as an index for the diagnosis of autistic children. Using classical methods of extracting different statistical features from the link and joint coordinates is one of the most common feature extraction methods in previous studies.[27]

Extracting statistical features from the movement of all joints and links can easily lead to the curse of dimensionality problem and its well-known consequences such as classifier overfitting risk and the need for a sufficient learning database. Furthermore, the statistical features may not be accepted by medical staff because of the lack of medical knowledge supports.

The purpose of this paper is to diagnosis the autistic children using features based on medical knowledge about their gait patterns and movement signs in an automatic and noninterventionist manner. Figure 1 is the block diagram and the applied methods of this paper. To this end, after reviewing the medical texts and information about autistic people's gait patterns, it was attempted to extract features of human gait pattern analysis, using the Kinect sensor data, representing the medical knowledge about this disease. For this purpose, certain joints of the body are identified, and their trajectory is tracked in the images. Then, the features based on the medical knowledge about the gait patterns of autistic individuals were extracted from the trajectory. In the other approach, statistical features were extracted from all the joint's position and their angels, and then the optimum features set is selected through the statistical test of analysis of variance (ANOVA). Then, using the selected features, the classification of the patient and healthy groups is performed. According to the achieved result, the joints that provide more valuable information about autistic people were recommended to implement an automatic diagnosis system using a few wearable sensors in conditions where Kinect sensors cannot be used such as crowded or low light places.

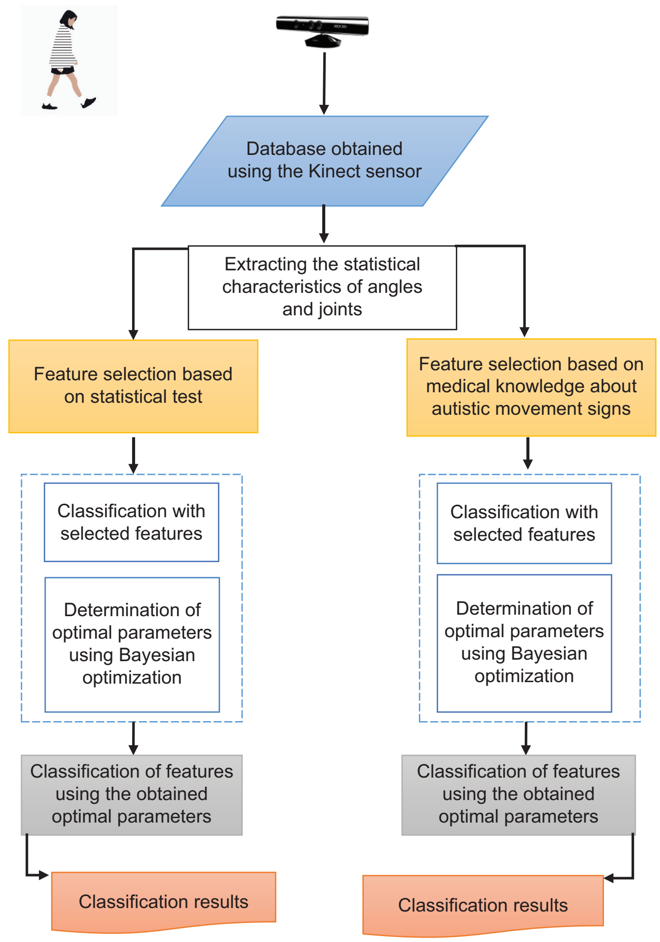

Figure 1: Block diagram of this research method

Related Works

Abdulrahman and Hadi detect autistic children's gait disorder using the Kinect sensor. This experiment was conducted on simple walking in the range of 1.5–4 m. The extracted features were the joint angle and the distance between legs that were classified using an artificial neural network.[3]

Zakaria *et al*. experiment with autism predict the severity of autism using a gait pattern. In this experiment, people walked in different ways against the Kinect sensor. Then, features such as step length, step speed, knee and ankle joint angle, toe distance, and motion range from all Kinect sensor data were extracted. Finally, using an artificial neural network and nearest-neighbor classifier, they could detect disorders in autistic people.[28]

In an experiment, Borges *et al.* investigated the characteristics of autistic children during walking. In this experiment, two subjects moved to each other, and their movement was recorded by a Kinect sensor. The features extracted in this study are angular velocity, angular acceleration, and mean of joint positions. Using statistical analysis, they reported the difference between autistic and healthy subjects. In this study, it was shown that in people with severe autism, the standard deviation of back angular velocity is significantly higher than those with mild autism.[29]

Ilias *et al*. conducted an experiment on simple walking with autism and healthy individuals. In this experiment, eight sensors, including Kinect and infrared sensors, were used for data collection. Then, the gait velocity characteristics, step length, and step time were extracted from the data. Finally, patients and healthy subjects were classified using the support vector machine (SVM).[30]

All the studies conducted were based on statistical information on joints, and none of them considered medical knowledge about movement signs and gait patterns of autistic individuals in the feature extraction process. In most of the papers, the length of the data is more than 1000, but in this paper, each time, the participant walked about two cycles in a distance of 1.5–4 m in front of the Kinect sensor.

Introduction to the Database

In this research, the open-access dataset of the article[3] has been used. This three-dimensional data set of Kinect sensor are collected by walking and moving of all children with autism spectrum disorders and healthy people. The database comprises 50 autistic children and 50 healthy children. For the healthy children, 26 men and 24 women were aged between 2 and 14 years and for the children with autism spectrum disorder, 42 were men and 8 women aged 5–15 years. All participants were examined before data recording to exclude subjects with lower extremity injury and any neurological or disease disorder, except autism, which can interfere with their body movement patterns. In this experiment, people were asked to move toward the Kinect sensor, and using this sensor, the position of the 25 joints and 16 angles between joints were recorded along with three coordinate axes.

This database is a 3D collection that combines gait and body movement analysis of children in controlled environments. Each subject's movement data is collected in three coordinates. At this base, the x-axis is 6 m to the left and 6 m to the right. For the y-axis, the movement is measured from mid-hip movement to 5 m up and 5 m down. The z-axis is the movement toward the Kinect sensor, the starting point of which can be measured from 0 to 8 m. To record data, children were asked to walk along a line at normal speed toward the Kinect sensor. Each time, the participant walked about two cycles in a distance of 1.5–4 m in front of the Kinect sensor.

Data Preprocessing

Based on the height of the participants in Figure 2, the average height of the two groups is significantly different, and autistic subjects significantly have a higher height than healthy subjects. Therefore, the position of joints in healthy individuals and patients is different because of their height. This condition causes the autistic children to be identified only based on their height regardless of symptoms associated with their disease. For this reason, initially, joint coordinates are normalized based on the height of the people, and then the feature extraction process is performed from normalized data.

Extracting Statistical Features from All Joints and Angles

Considering that in past studies, the extraction of statistical properties is one of the common methods. Hence, to compare the quality of extracted features based on the medical knowledge of motion pattern and gait of people with autism with previous studies, statistical features from all joints are also extracted. These features include mean, variance, skewness, and kurtosis of 25 joint positions along with all three coordinate axes, 16 angles between joints, the distance between each joint from the joint to the middle of the body, and distance of joints to the ground. In addition, the characteristics of stride length, stride width, walk time, time on the ground, time of walking, walking speed, maximum and minimum distance between legs, and knee joint position from the joint in the middle of the body.

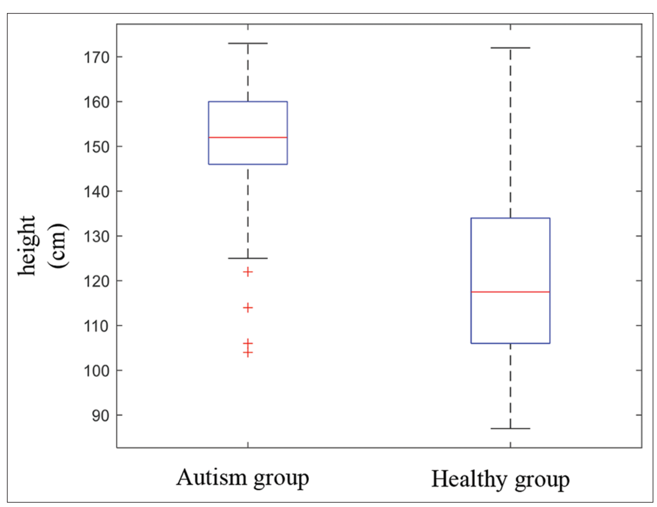

Figure 2: Box plot of the height of the subjects

Feature Extraction Based on Medical Knowledge about Movement and Walking Patterns of Autistic People

By studying the movement of autistic people, there were some features in these individuals' gate patterns, discriminating them from healthy ones. According to this knowledge, some indicators based on those features were extracted from the Kinect data. Based on movement signs, the excessive shaking of hands is one characteristic of autistic individuals, increasing the variance in the elbow's position and the wrist. Another prominent feature of autism is keeping the hands away from the body while walking, which increases the average angles between the elbow, shoulder, chest, and wrist, elbow, and shoulder joints. The last observed feature in these individuals is walking on the toes, which changes the mean of knee and ankle angles. The extracted features based on this information are provided in Table 1.

Features Selections using Statistical Analysis of Features

In the classification stage, among 1046 statistical features extracted using a statistical method, 42 features with $P < 0.00001$ in ANOVA statistical analysis have been selected. This optimum feature set is provided in Table 2. All the optimal positions of the joints chosen are based on the y-axis, which shows the difference in the movement of the joints up and down between the healthy and autistic groups.

Optimal Features Based on Medical Knowledge about the Gait Pattern of Autistic Individuals

ANOVA statistical analysis was used to evaluate the optimality of the selected features based on medical knowledge, which confirmed the optimality of the medical features according to $P < 0.05$. At the end, all 16 features have $P < 0.05$. These features include the mean of the joint position, the mean shoulder angle, the mean of hand joints to foot joints, and the mean distance between the finger joints and the ground.

Classification and Validation Method

In this paper, SVM, k-nearest neighbor, Naive Bayes, and AdaBoost ensemble classifier were used to diagnose autistic patients from healthy individuals. The hyperparameters of the classifiers were optimally selected through the k-fold cross-validation of training data and the Bayesian optimization method.

Validation

In this paper, the Leave One Subject Out (LOSO) cross-validation method is used. In this technique, the feature vector of one subject as the test data have been removed, and then the model is trained using the feature vectors of the others. This process is repeated for all the subjects. In this method, all the data are used for both training and testing, which leads to the optimization of the training process.

The results of classification using features based on medical knowledge about the gait pattern of autistic individual

Classification is performed using 16 statistical features selected based on medical knowledge. The hyperparameters of classifiers are optimized for each subject through LOSO cross-validation. To provide a unique classifier for all the subjects, the frequent hyperparameters selected for all the subjects selected as the hyperparameters of the final

Table 1: Features extracted based on movement signs in autism disorder

Motion cues	The names of the statistical features corresponding to the feature based on motion cues
Excessive movement of hands while walking	The variance of the elbow joint's position in the right hand along the X-axis
	The variance of the elbow joint's position in the right hand along the y-axis
	The variance of the left elbow joint's position along the X-axis
	The variance of the left elbow joint's position along the y-axis
	The variance of the right wrist joint's position along the X-axis
	The variance of the right wrist joint's position along the y-axis
	The variance of the left wrist joint's position along the X-axis
	The variance of the left wrist joint's position along the y-axis
Keeping the hands away from the body	The average angle between the sternum, shoulder, and elbow joints on the left side of the body
	The average angle between the shoulder, elbow, and wrist joints of the right body
	The average angle between the shoulder, elbow, and wrist joints of the left body
Walking on tiptoes	The average angle between the right hip, knee, and ankle joints
	The average angle between the hip, knee, and left ankle joints
	The average angle between the joints of the left knee, wrist, and big toe
	The average angle between the knee, wrist, and big toe joints of the right foot

classification model. The results of classification with the same hyperparameters for all subjects using medical knowledge-based features of the gait of autistic individuals are shown in Figure 3.

As can be seen, the highest accuracy (87%) is associated with the Ensemble classifier, and the lowest accuracy (73%) is related to the SVM classifier.

The results of the classification using the features selection based on the statistical analysis of the features

In addition to the features based on medical knowledge, classification was also done using 42 optimal features obtained through ANOVA analysis (with $P < 0.00001$). First, all the hyperparameters of the used classifiers were determined through heuristic methods of Bayesian optimization and 5-fold intersectional evaluation of the training data. Then, using the majority voting, the hyperparameters that are selected as the optimal parameters for the largest number of subjects are chosen, and the final classifier is trained using this classifier to create a classifier for all subjects. The results are presented in Figure 4.

As can be seen, the highest accuracy (84%) is related to the Naive Bayes classifier, and the lowest accuracy (81%) is associated with the SVM and nearest neighbor classifiers.

Discussion

In this study, the diagnosis of autistic children from healthy children was based on the classification of two categories of gait features. In the first phase, 16 medical knowledge-based features were obtained on the gait patterns of autistic children, and the classification of healthy and autistic children was done using these features. In the second phase, the classification of healthy and autistic children was done, using 42 statistical features were selected by ANOVA statistical test ($P < 0.00001$). Finally, to have an identical classification model for all participants. The frequent hyperparameters that were selected in different subjects' classification model were selected as unique hyperparameters of the classifier, and the classification was performed for all subjects using the same classification model.

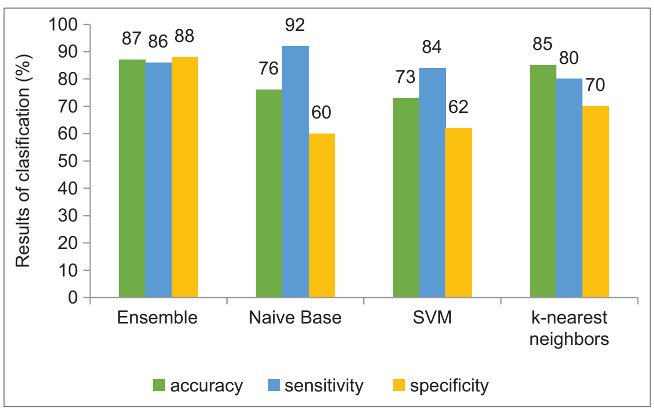

Figure 3: Bar graph of the achieved results using features based on medical knowledge about the gait pattern of the autistic individual

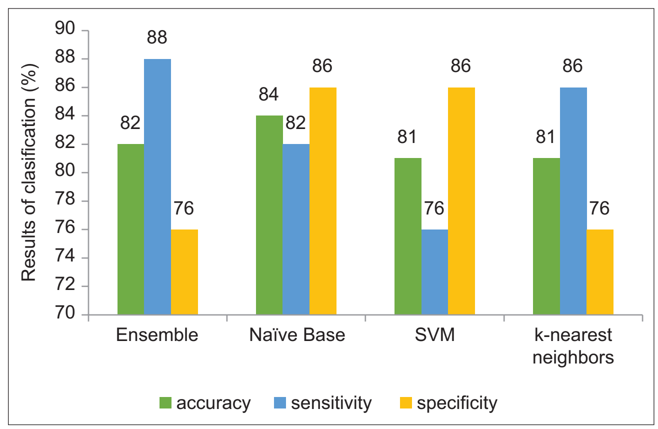

Figure 4: The results of the classification of the features based on the statistical analysis of the features

Table 2: Selected features based on statistical analysis that have a *P*<0.00001

Category	Feature name
The average position of joints	The average position of the middle spine joint, left knee joint, right knee joint, right elbow joint, left leg joint, right leg joint, left-hand joint, right-hand joint, left-hand tip joint, right-hand tip joint, left hip joint, head joint, right hip joint, left knee joint, right knee joint, neck joint, right shoulder joint, hip joint, sternum joint, thumb joint of the left hand, thumb joint of the right hand, left wrist joint, right wrist joint along the y-axis
Average of angles	Average left and right shoulder angle
The average distance between the joints	The average distance between the position of the left hand and left thigh joints, joints of the left hand and the rump, joints of the tip of the left hand and the left thigh, joints of the left hand and the rump, left hip joint and the rump, left hip joints and the left thumb, left hip joints and the right thumb, left hip joints and the left wrist, rump, and thumb joints of the left hand, rump and thumb joints of the right hand, rump and left wrist joints, rump joint, and the ground, joint of the left-hand tip and the ground, joint of the tip of the right hand and the ground
The variance of the distance between the joint and the ground	The variance of the distance between the position of the rump joint and the ground
The position of joints depends on the position of the rump joint	The position of the tip joint of the left and right hand depends on the position of the rump joint

Table 3: Comparison of classification accuracy using two categories of features

The size of the feature vector	Naive base	SVM	k-nearest neighbors	Ensemble (AdaBoost)
16 (extracted features based on medical knowledge about walking of autistic subjects)	0.76	0.73	0.75	0.87
42 (characteristics obtained using ANOVA statistical analysis)	0.84	0.81	0.81	0.82

ANOVA – Analysis of variance; SVM – Support vector machine

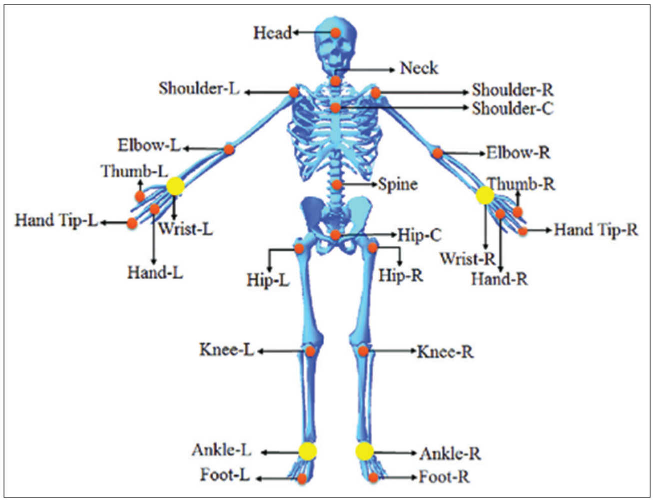

Figure 5: View of the human body's joints recorded using Kinect (selected joints based on the results of this study are shown in yellow)

According to Table 3, the results obtained in the ensemble classification have been able to overcome the dimension of the feature vector and provide acceptable accuracy using a small number of features obtained from medical knowledge. Based on Bayesian optimization, an optimal hyperparameter set is obtained for each individual. The AdaBoost method has been selected as the optimal parameter for more people in the Bayesian optimization process.

In this research, the processing method of a similar paper was modified, the number of features was reduced, and results were improved. In this study, the classification of healthy subjects from patients with autism was performed using the features extracted from a limited number of joints and angles based on medical knowledge of autistic children's movements.

One of the limitations of this study is the use of a ready-made statistical database that cannot determine things such as the gender ratio of people in the autistic and healthy groups. The ratio of boys to girls is 52% versus 48% in the group of normal children, whereas it is 84% versus 16% in the group of autistic children so it is not equal.

Previous research on the same database[3] extracted a high-dimensional feature vector with 1259 elements and applied PCA to reduce the feature vector size, causing a slow classification process and a high computational cost. However, this study achieved better results with a limited number of features (16 features) a lower computational cost.

In addition, in the previous research on this database,[3] regardless of the significant height difference between autistic and healthy groups causing significant difference in Kinect data in both groups, the classification of them was performed. In addition, given the large dimensions of the extracted feature vector, seven mathematical transformations were applied in data augmentation approach to overcome the curse of the dimensionality problem. However, in the training process, 70% of all data were selected for training, and 30% of them were selected for testing. Based on this method, the augmented data of an individual were used in both of the training and the test data. Hence, the classifier has prior knowledge about the label of different augmented data of the same subject. This current study eliminates the need to develop the augmented data set by reducing the dimensionality of the feature vector.

Finally, given that the Kinect sensor cannot be applied in environments where several subjects exist, so in environments such as kindergarten, where there are several subjects simultaneously, autism diagnosis can be solved using wearable sensors. This study introduces a limited number of joints and links containing valuable information and significantly affects the accuracy of the classification. This study showed that only having the information of four joints of the right wrist, left wrist, right ankle, and left ankle, autistic children can be classified as healthy ones with a high accuracy. This limited number of joints and links can be applied in wearable sensor systems in autism classification. In Figure 5, all the joints of the human body are shown, and four joints selected for the diagnosis of autism disorder are shown by the yellow circle.

Using the generalization of the method used in this research (medical knowledge), it is possible to diagnose diseases and other movement disorders in people. In such a way that by studying the medical knowledge about walking and then by matching these signs to the statistical characteristics, can classify sick individuals from healthy ones.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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