The Journal of Supercomputing (2021) 77:2590–2608
https://doi.org/10.1007/s11227-020-03357-0

A review on diagnostic autism spectrum disorder approaches based on the Internet of Things and Machine Learning

Mehdi Hosseinzadeh[1,2] · Jalil Koohpayehzadeh[3] · Ahmed Omar Bali[4] · Farnoosh Afshin Rad[5] · Alireza Souri[2] · Ali Mazaherinezhad[6] · Aziz Rezapour[2] · Mahdi Bohlouli[7,8]

Published online: 27 June 2020

Abstract
Children with autism spectrum disorders (ASDs) have some disturbance activities. Usually, they cannot speak fluently. Instead, they use gestures and pointing words to make a relationship. Hence, understanding their needs is one of the most challenging tasks for caregivers, but early diagnosis of the disease can make it much easier. The lack of verbal and nonverbal communications can be eliminated by assistive technologies and the Internet of Things (IoT). The IoT-based systems help to diagnose and improve the patients' lives through applying Deep Learning (DL) and Machine Learning (ML) algorithms. This paper provides a systematic review of the ASD approaches in the context of IoT devices. The main goal of this review is to recognize significant research trends in the field of IoT-based healthcare. Also, a technical taxonomy is presented to classify the existing papers on the ASD methods and algorithms. A statistical and functional analysis of reviewed ASD approaches is provided based on evaluation metrics such as accuracy and sensitivity.

Keywords Autism spectrum disorder · Deep Learning · Machine Learning · Internet of Things · Systematic review

1 Introduction

Autism spectrum disorder (ASD) is a neurodevelopment disability specified by severe weakness of social communication and behaviors. Based on Jon Baio [1], almost 1 in 59 children has a diagnosis of ASD. All of disabled children need special care and welfare facilities more than healthy kids. This lifelong disorder not only limits the life of the persons, but also negatively affects their caregivers' Quality of

✉ Alireza Souri
souri.a@iums.ac.ir

Extended author information available on the last page of the article

Life (QoL). Systems based on the Internet of Things (IoT) devices provide many useful features that facilitate remote monitoring of patients. Consequently, healthcare applications using the IoT devices have begun to attract attention in recent years [2–4]. Usually, IoT sensors and devices such as GPS, heart rate, microphone, and ear clips [5] embedded in wearable devices such as smartwatches as well as smart phones, belts and vice versa. Autism children are identified by sensors and gadgets rather than classical diagnosis methods [6].

During the past decade, a lot of articles have been published with the goal to detect a cure or an effective factor to prevent children from lifelong diseases. But, no remarkable results were accomplished. Hence, early diagnosis and the patients' QoL improvement are the most critical aspects of helping the patient. A considerable number of autistic children are not diagnosed before the age of two. Also, they still have a significant disability to do their routine activities. As a result, this paper investigates different approaches used by means of the IoT devices for children with ASD to present and compare new manners for diagnosing the disease or improving the QoL of already diagnosed patients. More specifically, IoT technologies are utilizing Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) to recognize emergency circumstances and accordingly protect patients from physical and mental harms [7]. These types of systems gather vital signs from the patients and then apply different ML and DL algorithms to identify suitable reactions. They could even support early diagnosis of ASD based on collected data from IoT devices. For instance, if autistic children get irritable, they will do dangerous behaviors that can be harmful to their physical health. At that moment, smart devices send alarms to their caregivers and doctors and report the condition and ask for a help. All such types of IoT-based equipment identify vital signs and examine the changes based on various evaluation factors (e.g., accuracy, sensitivity, specificity, and time).

To the best of our knowledge, there is no comprehensive and detailed review study on the ASD approaches. In this paper, a systematic literature review (SLR) is proposed to identify current trends, prospects, and possible gaps related to the use of IoT, ML, and DL in order to employ emerging technologies like mobiles, robots, and wearable devices in the field of ASD. The technical taxonomy is presented to classify the existing ASD methods and algorithms using IoT-based devices with the help of ML and DL. We categorize the ASD methods into two main topics, including approaches for diagnosing and measuring the disease severity of children with ASD and plans for improving the QoL for children with ASD.

The main contributions of the proposed SLR on ASD approaches are as follows:

- Presenting a review and analyzing ASD approaches using IoT-based devices, ML and DL algorithms by covering 28 research studies.
- Presenting a technical taxonomy of ASD methods and applied algorithms using IoT-based devices.
- Analyzing and discussing the technical evaluation factors of each research study.

This paper is organized as follows: Sect. 2 provides related work, continued by Sect. 3, which discusses the methodology and research planning. Section 4 illustrates a technical taxonomy for ASD approaches and a side-by-side analysis and

summary for each research study based on the presented taxonomy. Section 5 presents an analytical discussion based on the reviewed research studies. Section 6 presents open issues and new challenges facing ASD. Finally, the conclusion is illustrated in Sect. 7.

2 Related work

Making interactions with autistic children is one of the most difficult and challenging issues that their families and caregivers deal with. In the last years, IoT-based systems and further computer-aided therapy methods received massive attention. Several articles have been committed to ASD therapy or diagnosing the diseases, but a few numbers of relevant papers were presented to investigate ASD in the same way.

Closely related to our work, Jayatilleka et al. [8] focused on challenges in various smart devices, sensors, and systems related to health conditions. According to [7], IoT is an emerging technology in the modern information age. In healthcare, a remarkable number of wearable sensors are used not only to monitor body parameters such as heart rate, but also to store obtained data for decision-making. The primary components of this technology are IoT, cloud computing, and Wireless Body Area Network (WBAN).

Also as Helmy et al. [9] mentioned children with ASD like dementia and Alzheimer's patients suffering from forgetfulness. Hence, they tend to get into dangerous situations, for example, escaping from home. However, children with ASD could avoid leaving their safe zone by using this technology. They proposed the Alzimio application to solve these kinds of problems by means of IoT devices. In regard to these issues, Aisuwarya et al. [10] presented a method to display the exact position of patients in the smartphones of their caregivers. In particular, when the patients have been outside their safe zone, these systems could be useful.

In a brief survey paper on ASD, Ida Seraphim et al. [11] applied various types of data mining methods such as classification, regression, and clustering for early detection of ASD. Early diagnosis of ASD is an essential factor in providing appropriate education and support services to patients and their caregivers. Their investigations showed that the classification algorithms have the most accuracy in the diagnosis of the disease.

Leroy et al. [12] have examined the effects of data mining techniques on autism therapy, because it is a treatment for increasing appropriate behaviors. This technique can predict the behavior of autistic children and understand their reactions better. They applied decision trees and associate rules to recognize proper and inappropriate actions.

On the other hand, Hyde et al. [13] investigated 45 articles using applications of supervised ML and classification algorithms in ASD. They realized that the articles mostly used Support Vector Machine (SVM), Random Forest (RF), Decision Trees (DT), Least Absolute Shrinkage and Selection Operator (LASSO), regression, Neural Network (NN), Elastic Net regression (ENet), Conditional Forest (CF), Naïve Bayes (NB), flex tree and random tree. Koumpouros et al. [14] have presented a

survey investigating 83 articles published after 2000. The papers committed to the intervening of wearable technologies and computing capabilities in ASD.

Robins et al. [15] presented a part of the AuRoRA project in a research article and tried to use the Robota robot instance, a useful toy for autistic children. Due to the Conversation Analysis (CA), an in-depth evaluation factor, they investigated it changes in three kids with autism. Therefore, they realized that the children interact with the robot-like adult. The research project not only focused on a new definition of the autistic kid's joint attention, but also illustrated the importance of computer and robot therapy for ASD.

3 Research methodology

In this section, we apply the systematic literature review (SLR) process proposed by [16] existing ADS approaches. The SLR is collecting relevant articles that identify particular research topics and questions. According to the methodology, Fig. 1 shows three stages: collecting, refining, and analyzing.

Searching for the related articles was begun in March 2019. The primary databases and resources applied were IEEE, ACM, Science Direct, Springer, Wiley, Google Scholar, and then SCOPUS was added. More than 65 articles were investigated to find the most relevant papers to the review literature by applying some inclusion and exclusion factors. In the first stage, the papers published between 2014 up to March 2020 relating to ASD using IoT-based devices were considered. PICO Stone [17] tried to use the most relevant keywords that include ASD, autism, IoT, internet of things, wearable sensors, social robot, robot therapy, smartphone, smartwatch, Kaspar robot, and ADHD. Besides, survey and review papers, non-English context, and non-peer-review procedures relinquished. Eventually, 28 articles were extracted that were committed to ASD using IoT-based devices.

Figure 2 illustrates a statistical time duration of ASD using IoT-based devices studies per publication year.

The final result of research selection collected 28 research studies which were:

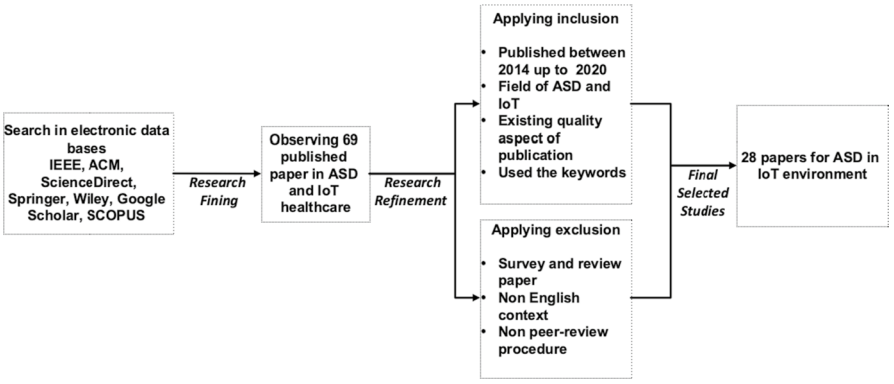

Fig. 1 Research finding methodology based on the SLR

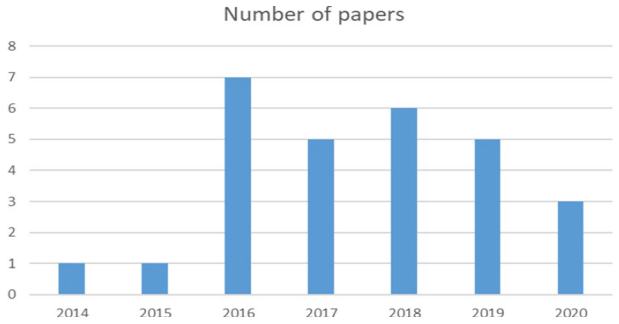

Fig. 2 Publication per year analysis for ASD approaches

- Published in the ASD topic
- Clarified the proposed method obviously and motivated
- Studies published in English
- Presented a research methodology based on simulation, formal, statistical and implementation results
- Papers must be in a full version (not abstracts).

In the analysis process for every research study, the following analytical questions were designed for responding to technical aspect of the SLR method on the ASD approaches:

RQ1 Which ASD approaches are analyzed and evaluated in this review?
RQ2 Which methods and techniques are applied for ASD approaches?
RQ3 What are the evaluation metrics for ASD improvement?
RQ4 Which scientific publishers are distributed in ASD?
RQ5 Which sensors and platforms are developed for ASD approaches?

4 ASD approaches

Autism disorder is one of the incurable diseases and the patient should live with it during their whole life. But it might be predicted quickly to apply the therapeutic methods as soon as possible. In this section, significant research on ASD is considered. The articles require more consideration to develop more effective and efficient ASD methods. According to Fig. 3, our research methods included two parts in the following subsections which are approaches for diagnosing and measuring the disease severity for children with ASD and plans for improving the QoL for children with ASD. To achieve these goals several methods were applied by the following research studies, which included data mining, feature selection, genetic algorithm, reporting, virtual reality, DL, electroencephalography (EEG), object-oriented, and peer-to-peer (P2P).

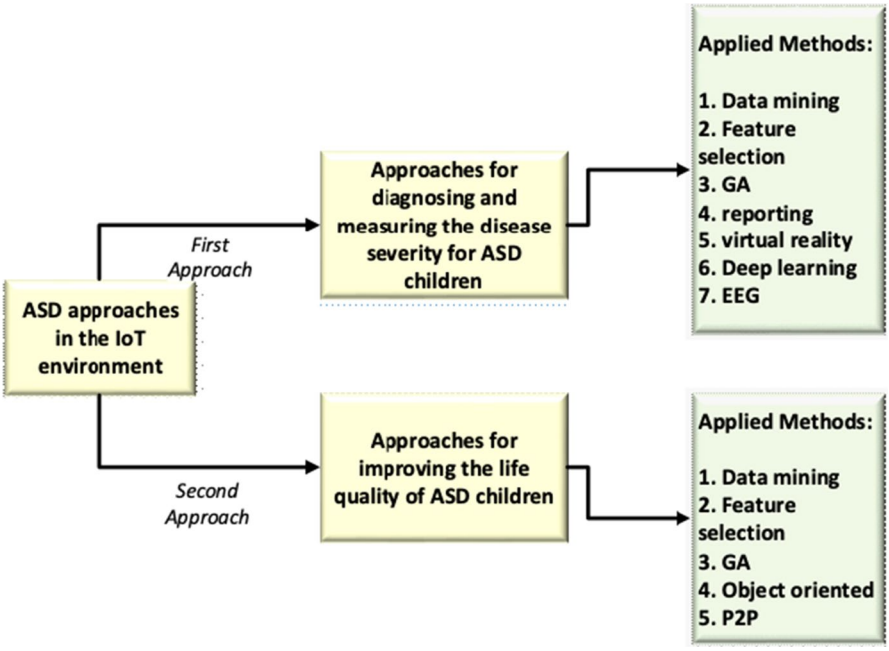

Fig. 3 Presented taxonomy for the ASD approaches

4.1 Approaches for diagnosing and measuring the disease severity for children with ASD

One of the problematic issues of ASD is prediction and measurement. Autism has very different vision that has effects on healthcare and educational assistive systems. The disease is typically predicted in 2- or 3-year children in mild and severe ranges but, with the help of IoT platforms, the process has accelerated. This improvement helps to provide appropriate healthcare and educational services for the patients. Table 1 illustrates the main idea, applied method, sensors, and platforms, and evaluation factors investigated.

Sundhara Kumar et al. [18] proposed a framework for automatic monitoring of health conditions by wearable sensors that are reading users' brains. The obtained data were continuously sent to caregivers of autistic people. They focused on brain signals which are captured by the sensors, and if the patients are in a dangerous condition, health description is sent to their caregivers and doctors. The brain data give more accurate results to predict the disease.

Yang et al. [19] have presented a wearable technology based on social sensing through IoT environment to collect physical signs, environment sensing, privacy audio feature integration, and behavior monitoring. The wellbeing monitoring platform produced privacy audio wellbeing features to evaluating speech quality and information without preserving raw data of audio. They developed the app on android devices and servers to explain the dependency between physical and

Table 1 Comparison of the approached for diagnosing and measuring the disease severity for children with ASD

References	Main idea	Applied method	Platforms	Evaluation factors			
				Accuracy	Sensitivity	Specificity	Time
[18]	Monitoring health condition from brain signs	Data mining	Smartphone	✓	✗	✗	✓
[19]	Using wearable technology to monitoring mental health in the long term	Reporting	Smartwatch, smartphone	✓	✗	✗	✓
[20]	Utilizing IoT for healthcare monitoring	Feature selection	Temperature sensors, Arduino	✓	✗	✗	✗
[21]	Avoid preventable injuries from autistic individuals	GA	Smartphone, wearable sensors	✗	✗	✗	✗
[22]	Using emotion and images to a smart home environment	DL	Smartphone, temperature sensors	✓	✗	✗	✗
[23]	Perceive emotion recognition of autistic children	DL	Thermal imaging camera, Arduino	✓	✗	✗	✗
[24]	Monitoring activity of the autistic person can may harmful	Feature selection	Smartphone, smartwatch	✓	✗	✗	✓
[25]	Early detection of autism disorder	Feature selection	Smart toy car	✓	✓	✓	✓
[26]	Virtual reality therapy to perceive the situation of autism kids	Virtual reality	Smartphone, wearable sensors	✗	✗	✗	✓
[27]	Aa robust method to early diagnosis of ASD in children	Feature selection	EEG	✓	✓	✓	✓
[28]	Infant detection of autism by a data analysis framework	Data mining	EEG	✓	✓	✓	✗
[29]	ASD detection through ML	Feature selection	Wearable sensors	✗	✗	✗	✓

psychological state information of their case study in the long term. Also, it could be applied to real patients and go on clinical trials. Also, Krishna et al. [20] proposed an IoT system for monitoring vital patient parameters and health conditions. These data transferred from a smartphone or other devices to the cloud server. Through cloud computing and the help of the extracted parameters that are heart rate, percentage of oxygen saturation, and body temperature of patients we can diagnose the user's health status. The data come from their mobile and are displayed on a laptop or smartphone software like an MQTT lens.

On the other hand, Eshetu et al. [21] designed a service-oriented architecture (SOA) based on IoT for people with an autism disorder by several sensors. The proposed wearable sensors obtain physiological information about autistic individuals and the condition of surroundings patients. Mano et al. [22] proposed an IoT therapeutic technology for disabled patients and older adults at home by using cheap and available equipment like smartphones, cameras, and wireless objects. They utilized image processing and embedded computing on patient treatment and helped them in health smart home. The authors defined some evaluation factors, such as accuracy and computational performance. Probably, this method can improve the facial expression and be used not only on children with ASD, but also for Parkinson's patients. Lavanya et al. [23] have presented a way for autism children to perceive their emotions through some of the behaviors and reactions such as voice pitch, communication without speech, sophisticated strategies, and thermal picture.

On the other hand, Amiri et al. [24] presented an IoT framework that utilizes a smartwatch to detect stereotyped behaviors of autistic children. The smartwatch is made by an inbuilt accelerometer to detect and identify three common reactions of children with autism which are sobbing, hand flapping, and painting. Their framework is getting data through sensors and then sending it to the cloud to comprehensive analysis. The process affects the decision trees and increases their accuracy, which means this technology is beneficial for parents, clinical information decisions, and caregivers. Moradi et al. [25] applied an intelligent toy car for the most essential obstacle of the treatment stage, which is early diagnosis. The SVM algorithm had been utilized in the toy car to distinguish healthy children and autistic children. Their experimental result showed that healthy kids play with the car's wheels fewer than autistic kids, so this approach has the most accuracy, sensitivity, and specificity. Manju et al. [26] have presented a therapy-based virtual environment that has different levels to reinforce the emotion, attention, and social relationships of autistic children. First of all, the environment attracts attention through color lights and loud sounds, then focuses on improving social relations and interaction using touching and throwing a ball. The third step is epitomizing decision-making. Virtual reality rehabilitation therapy can predict in which stage autistic kids get panic, frustrated, and become eager.

Abdolzadegan et al. [27] presented a robust method for early detection of children with ASD through linear and nonlinear feature selection to describe and analyze EEG signals. Some essential criteria for feature selection were mutual information (MI), genetic algorithms (GA), SVM, and K-nearest-neighbor (KNN). They achieved the highest accuracy in SVM and KNN. However, the proposed method did not support complicated classifications, such as deep neural network and hybrid

approaches. Shankar et al. [28] designed a framework to diagnose autism infants by applying data analysis and ML algorithms. Also, their structure utilized the in-depth concept of data analysis and training data models with the help of SVM. The technique achieved 89% accuracy, but must be developed based on DL and biomedical imaging for increasing efficiency. Praveena et al. [29] applied ML algorithms for the early detection of ASD in enough time to present the best treatment. They evaluated their own algorithm in the data of the UCI dataset. The method can be extended to collaborate with other ways of diagnosing ASD, such as EEG and MRI images. However, the intelligence detective needs to be developed for different ML algorithms, in particular SVM and DL methods.

4.2 Approaches for improving the QoL for children with ASD

Improving the QoL of children with ASD is an important issue. Some relevant factors in connection with the QoL of children with ASD have been examined is few research studies. Table 2 provides more detail about these research works.

Alam et al. [30] presented an IoT system. The Belief Rule Base (BRB) collects symptoms and signs data of children with autism by the pervasive sensor nodes to classify various types of autistic children. They used different sensors to assess their social interaction, behaviors, and heart rate. The system's criteria are rule weight, belief degree of the patient. However, more sensors and IoT systems could be employed to improve their accuracy. Rahman et al. [31] designed a platform for individual needs of children with ASD, which analyzed physiological signs and used collected and converged application data. The architecture of the wearable system included an array of sensors, several embedded wearable sensors, and medical servers to perceive the healthcare status of autistic children. The multimodal intelligent mode enhances the daily activities of patients by means of sensors and all other embedded gadgets. But the wearable feature used in a laboratory environment is not comfortable, so it cannot be used in industry or for daily activities. Also, Shi et al. [32] has presented a wearable technology to investigate the interaction and behavior of children with ASD in a classroom. Generally, the objects of technology use observational methods for improving the social skills of ASD. This method suggests the best feedback and reaction to teachers, which enhances their classroom interaction.

One the other hand, Sumi et al. [33] have presented a fuzzy assistive method, which reduces dependency a lot. The system collects data from various sensors and generates it to the assisting persons and helps restore disorder. With the help of wearable sensors, if the kids gets injured or hurt, assisting people will be quickly notified. Tang [34] has presented a method based on IoT to comprehend emotions by facial statement and body movement of the ASD. Because it is one of the most challenging problems for neuro-typical individuals, they tested various sensors to apply emotion labels to emotion APIs and the systems training prediction emotion. Also again, Tang et al. [35] have presented a picture exchange communication system that assists the system for ASD to express their activities and items and help families, caregivers, and teachers use this system. If their extracted data by sensing tools shows that social communication is in terrible condition, the system automatically

Table 2 Comparison of the approaches for improving the QoL for children with ASD

References	Main idea	Applied method	Platforms	Evaluation factors			
				Accuracy	Sensitivity	Specificity	Time
[30]	Assessing the spectrum of children with autism	Data mining	Arduino, ear clip, GPS	✓	✗	✗	✓
[31]	Perceiving special needs of autism children through IoT sensors	Data mining	Wearable sensors	✗	✗	✗	✓
[32]	Providing best feedback to teachers of autistic children	Data mining	Wearable sensors	✓	✗	✗	✓
[33]	Making independent of the autistic student from assisting people	Data mining	Wearable sensors, GPS	✓	✗	✗	✓
[34]	Perceiving emotion of ASD	Data mining	Arduino	✓	✗	✗	✗
[35]	Recognizing the need for ASD through PECS	Data mining	Smartphone	✗	✗	✗	✓
[9]	Developing an app to autism disorder	Genetic algorithm	Smartphone	✓	✗	✗	✓
[36]	Training to autism child through robots and improve their abilities	Reporting	NAO robot	✓	✗	✗	✓
[37]	The proposed technical solution for parent ADHD	Feature selection	Smartwatch, smartphone, wearable sensors	✗	✗	✗	✓
[38]	Trying to understand how intelligent objects help the autistic	Object-oriented	Wearable sensors	✓	✗	✗	✗
[39]	Doing activities that autistic kids could not do before by intelligent devices	P2P	SmartBox devices	✗	✗	✗	✓
[40]	Improving heuristic diagnostic problem of the autistic student during the learning	P2P	SmartBox devices	✗	✗	✗	✓
[41]	Using Kaspar robot to enhance social and communication skills of ASD students in Greek	Reporting	Kaspar robot	✗	✗	✗	✗
[42]	To compare gesture recognition of children with ASD between human- and robot-based intervention	Reporting	NAO robot	✓	✓	✗	✓
[43]	To design a companion assistive IoT-based for patients with ASD	Feature selection	Arduino	✓	✓	✗	✓
[2]	Robot assistant to improve narrative skills of Chinese-speaking preschool	Reposting	NAO robot	✗	✗	✗	✗

sends autistic individuals' descriptions to their assisting people. But, the employed sensors are not yet sufficient to cover all of the dangerous and terrible situations.

Furthermore, Helmy and Helmy [9] provided a mobile app to demonstrate the effect of geo-fencing of the safe zone and activity recognition of autism, Alzheimer's, and dementia disorders. The Azimo is an IoT-based app that should run in many devices with different hardware. The authors proposed an android app through investigating activity recognition algorithms and improved accuracy and efficiency with minimum delay. Liu et al. [36] introduced a platform based on instructions of speech and imitation. The authors presented a robot to imitate ASD or vice versa. The humans adjust the guidance of the robot and it is asked to match the autistic kid actions like a coach, teacher, etc. This motor learning technique improves the imitation and social communication skills of the child with autism, also it analyzes behaviors and sends feedback to their assisting people. However, DL and neural language processing could be improved through some other complex conversations.

Einarson et al. [37] identified an approach to solve the problem through the energy path and life balance of IoT devices. The prototype systems are influenced by IoT common and structure. They are going to improve the participatory actions of intended end-users based on the identification of stress and make a connection between the devices. Grimaldi et al. [38] have presented a smart object-oriented device that has a tangible impact on improving the QoL of autistic people based on IoT. They classified the various types of autism by intelligent objects and platforms. Furthermore, the most useful devices and objects are divided into three categories: social interaction enablers, learning supporter, and behavior inhibitors. This classification helps to eliminate the unique needs of every one of the autistic people and disabled individuals.

Sula et al. [39] have presented an IoT and peer-to-peer (P2P) based approach, which helps to improve the QoL of autistic kids. Children with autism become excited by gadgets and devices such as smartphones, computers, and touch screen tablets. The smart devices make children thinking about their decisions, feelings, needs, etc. Many of skills such as vocabulary, mathematical, and social interaction are thought to increase concentration and QoL in autistic children. Sula et al. [40] presented an environment to students who are diagnosed with ASD. Their approach is based on IoT and P2P with various visual systems such as pictures and images, realistic drawings, objects, written words, etc. The research was presented to improve and extend their previous article with some differences. For example, they identified the advantages and disadvantages of different tools for autistic students in mathematics.

Also, Karakosta et al. [41] have illustrated using the Kaspar robot as a therapeutic tool for 7 ASD students in a Greek school. The research focused on the influence of using Kaspar on some behavior of the patients such as communication and interaction skills, prompted speech, unprompted imitation, and attention. Eventually, the positive impacts of the clever therapeutic way, especially in talking and communication skills, surprised the patients' teachers. Their evaluation factors included eye gaze, focus-attention, gesture recognition, imitation prompted and imitation unprompted. On the other hand, So et al. [42] assigned 23 autistic children into two human and robot-based teaching groups. After that, they compared these two types

of serving methods in production and recognition of new gestural. Eventually, there was no difference in feedback accomplished by both groups. In other words, all gestural behaviors of children depend highly on the structures of their lessons that can work in some assistive technologies to have a significant impact on the gesture learning of children with ASD.

Khullar et al. [43] have proposed an IoT companion for hypersensitive individuals with ASD through presenting a prototype to identify and control the sensory and surroundings of patients. Their proposed technique detects and fetches the information of sensory via electronic sensors. The method is confirmed by 93% of caregivers, but can be more intelligent with the help of ML, DL and VR algorithms. A robot-based interaction way for preschool children with ASD to improve their narrative skills has been proposed in [2]. They utilized the NAO robot to help communication relations and gestures between Chinese-speaking patients. Their results show that the kids can have more productive conversation with robots, compared to the medical doctors. But, the study was not able to remarkably improve their gestures.

5 Discussion

This section presents a comparative and technical analysis of existing ASD approaches. According to the already stated analytical questions in Sect. 1, some technical and statistical answers responded as following:

5.1 *RQ1* Which ASD approaches are analyzed and evaluated in this review?

Figure 4 illustrates the percentage of existing approaches in ASD. It is evident that most articles are committed to improving the QoL for children with ASD. This approach has 16 research studies for the evaluation of autism disorder. On the other hand, 12 articles analyzed all feasible ways to diagnose and measure disease severity. Since autism has no cure and is a lifelong disease, improving the QoL of autistic

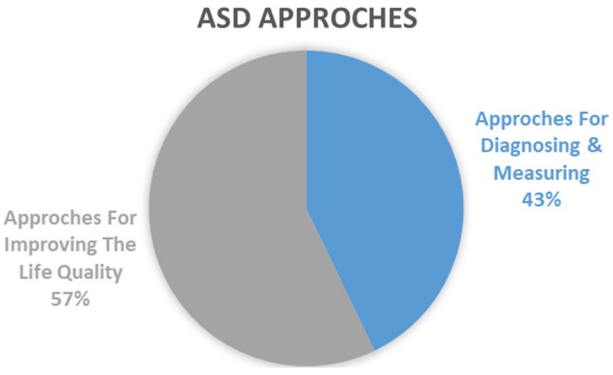

Fig. 4 Variety of ASD approaches in the literature

people is very necessary, and a strong motivation to conduct further research in this field.

Moreover, the parents or caregivers diagnose autism, and its severity at latest when children are 3 years old and provide therapeutic solutions. But, the early diagnosis of autism has many advantages.

5.2 *RQ2* Which methods and techniques are applied for ASD approaches?

Based on Fig. 5, data mining methods are the most used ones. Data mining applied to large volumes of data mainly by means of pattern recognition techniques. Reliable early detection and other various healthcare-related systems have emerged from the clinical and diagnosis data by data mining and the healthcare industry. Also, the data mining methods cover generalization, characterization, classification, clustering, association, evolution, pattern matching, data visualization, and meta-rule-guided mining. In this literature, we observed that the data mining methods are used mostly in QoL improvement approaches for children with ASD. But, this technique can mostly be applied on wearable sensors and smart devices that gather data. It should be stated that such equipment does not have enough intelligence techniques. Therefore, it is used in a controlled environment instead of a real environment.

The feature selection and reporting methods get second and third places of popularity in this research. The feature selection methods based on GA or other algorithms reduce dimensionality by selecting a subset of original input variables. The reporting techniques belong to papers that utilized the robot as a way to improve the QoL of the patients. The reporting technique is used to compare the impression of human and robot-based therapy. As a result, they have sufficient speed, but need more development.

Also, GA, DL, and P2P techniques included in recent papers that provide several services for patients with ASD using AI. To use GA for parallel computing that was accomplished through the IoT equipment, the methods have adequate speed, but lack acceptable accuracy.

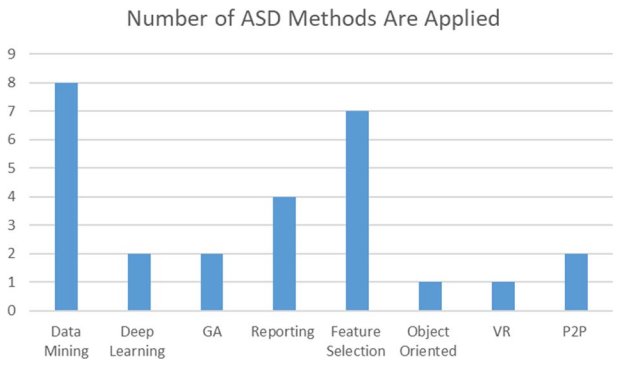

Fig. 5 Percentage of methods used in ASD approaches in the literature

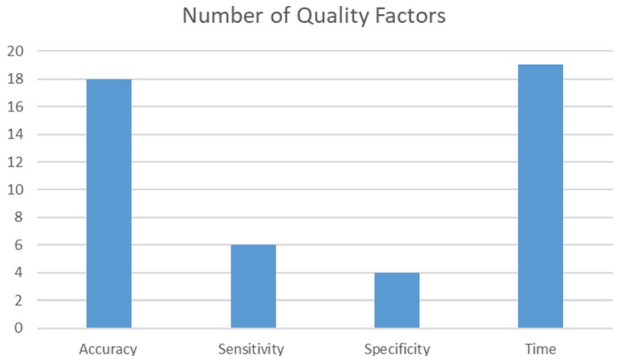

Fig. 6 Comparison of quality factors in the ASD approaches

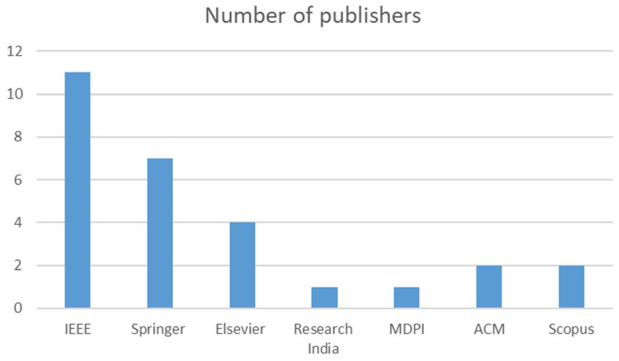

Fig. 7 Some publishers in existing papers of the ASD

5.3 *RQ3* What are evaluation metrics for the ASD improvement?

According to Fig. 6, the research studies have been evaluated with some quality factors such as accuracy, sensitivity, specificity, and response time in the ASD methods. We observed that the response time and accuracy were the most important quality factors in IoT-based ASD diagnosis devices and systems. In general, we mentioned four routines and basic factors, but other important factors could be evaluated, such as CCR, precision, computational performance, etc.

5.4 *RQ4* Which scientific publishers are distributed in ASD?

According to Fig. 7 and applied SLR methods on the ASD studies, 11 papers among 28 selected research studies have been published by IEEE. Hence, IEEE has the highest number of investigated papers.

5.5 *RQ5* Which sensors and platforms are developed for ASD approaches?

According to Fig. 8, selected research studies use different sensors and platforms for ASD approaches. We have defined all advanced sensors and gadgets such as pulse oximetry, EMG sensors, GSR sensors, and smart belt in the wearable sensors' category.

6 Open issues

According to the above analytical results, there are some open issues and new challenges in developing IoT-based approaches for children with ASD. These issues not have been comprehensively analyzed yet, but some of them are explained in the following:

- For diagnosing and measuring the disease severity for children with ASD, object-oriented segmentation methods help to eliminate the individual needs of children with autism.
- One of the main open issues in the approaches for improving the QoL for children with ASD is using various robots. It is used for the imitation of moves and simultaneous speech instruction and evaluates the autistic functions.
- Wearable devices are used in all classified approaches (pulse oximetry, EMG, GPS, GSR, etc.) to predict and measure autism, also assist in the daily activities of patients. The sensors can be embedded in every device or worn directly.
- DL is one of the foremost open issues in ASD prediction and diagnosis, which is used to identify disorders in several ways such as brain imaging and using multi-side databases.

Some essential factors on the ASD using IoT-based devices have been introduced briefly as new challenges as follows:

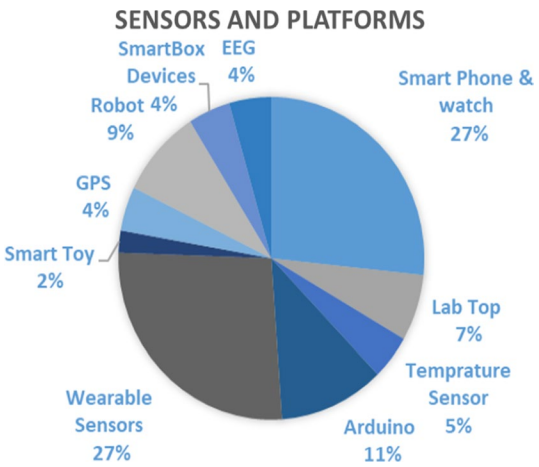

Fig. 8 Comparison of sensors and platforms in the ASD approaches

- Integrity: integrity of all data has to be maintained during the process of data transmission among devices and make it complete and safe to the destination.
- Availability: makes it available among all of IoT-based services for healthcare such as local, global, and cloud services to the allowed section, when needed even in the presence of various attacks.
- Self-healing: due to the probability of failure or running out of medical devices function, self-healing is one of the most critical features in the IoT-based networks. Then, other collaboration devices should enable minimum-security level.

7 Conclusion

The use of IoT devices has an important impact on improving the QoL of patients with ASD. Choosing the right IoT services for autistic children is one of the main challenges in autism disorder. There are many different sensors, platforms, and methods in ASD, which often have high impact on the children. This paper provided a systematic review of the ASD approaches published between 2014 and 2020, in which 28 research studies were considered through the analytical comparison. The number of published papers is determined almost high in 2016 and 2018. The IEEE publication with 51% has the highest rate of published papers. We classified selected 28 research studies in 2 categories of (1) diagnosing and (2) supporting improvement of patients' QoL. Almost 43% considered of selected publications focused on the approaches for diagnosing and measuring the disease severity for children with ASD, and 57% considered improving the QoL for children with ASD. Also, all selected approaches compared using some factors such as evaluation factors in terms of accuracy sensitivity, specificity, and time. Based on the presented cases, a comparative analysis was made between the ASD approaches and IoT-based devices. The results have shown that most research studies try to improve the QoL of autistic children. The study of variant ASD approaches using IoT-based devices will be useful in the design of new ASD approaches and devices to increase helpful services for autistic people.

According to technology's expansion, IoT-based systems can protect old methods of ASD. Also, some articles prove that children with ASD are more interested in being supported by robots rather than humans. For instance, children with ASD have more stable eye contact concentration with the NAO robot in contrast to another regular classroom [44]. Furthermore, contrary to the classic ways to protect the patients, using IoT systems reduces caregiving and supporting costs and are easy to use.

On the other hand, emotional aspects can also affect the quality of human-based therapy, in which is not a concern in systems based on various sensors and robots. IoT techniques must be developed for an unpredictable world, and behavior of robots should approach humans' behavior. To meet the purpose, affective and cognitive computing must be added to robots or other technologies that interact with humans.

This review has some limitations as follows: (1) we reviewed only research studies, which have been found and selected using following keywords: "autism spectrum disorder (ASD), internet of things (IoT), and ASD in IoT"; (2) non-English

journals were omitted from this examination; (3) this evaluation ignored chapter books and thesis. We believe that some research regarding the ASD approaches using IoT-based devices have also been discussed and published in other languages.

Acknowledgements This paper derives from the Research Project with code 98-1-37-14862 and Approval ID IR.IUMS.REC.1398.308.

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Affiliations

Mehdi Hosseinzadeh[1,2] · Jalil Koohpayehzadeh[3] · Ahmed Omar Bali[4] · Farnoosh Afshin Rad[5] · Alireza Souri[2] · Ali Mazaherinezhad[6] · Aziz Rezapour[2] · Mahdi Bohlouli[7,8]

Mehdi Hosseinzadeh
hosseinzadeh.m@iums.ac.ir

Jalil Koohpayehzadeh
koohpaye.j@iums.ac.ir

Ahmed Omar Bali
ahmed.bali@uhd.edu.iq

Farnoosh Afshin Rad
radfarnush@gmail.com

Ali Mazaherinezhad
mazaheri.a@iums.ac.ir

Aziz Rezapour
Rezapour.a@iums.ac.ir

Mahdi Bohlouli
me@bohlouli.com

[1] Institute of Research and Development, Duy Tan University, Da Nang 550000, Vietnam

[2] Health Management and Economics Research Centre, Iran University of Medical Sciences, Tehran, Iran

[3] Department of Community Medicine, Preventive Medicine & Public Health Research Center, Iran University of Medical Sciences, Tehran, Iran

[4] Diplomacy and Public Relations Department, University of Human Development, Sulaymaniyah, Iraq

[5] Department of Computer Engineering, Shahr-e-Qods Branch, Islamic Azad University, Tehran, Iran

[6] Department of Sports Medicine, School of Medicine, Hazrat Rasool Hospital, Iran University of Medical Sciences, Tehran, Iran

[7] Department of Computer Science and Information Technology, Institute for Advanced Studies in Basic Sciences, Zanjan, Iran

[8] Research and Innovation Department, Petanux GmbH, Bonn, Germany