



# IoT based assistive companion for hypersensitive individuals (ACHI) with autism spectrum disorder



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## ABSTRACT

**Objective:** Today, most of the individuals with Autism Spectrum Disorders (ASD) have atypical sensory behaviors. The main aim of this study is to propose an assistive intervention for supporting the overloaded sensory responses in hypersensitive individuals with ASD.

**Methods:** The vision, auditory, smell, and physical balance related multi-sensors based hardware prototype, namely Assistive Companion for Hypersensitive Individuals (ACHI) has been designed for individuals with ASD. The proposed ACHI prototype is an assistive-technology based companion for hypersensitive individuals with ASD which is able to ‘fetch/detect the sensory information using electronic sensors’, ‘making the decision using fuzzy logic on the basis of fetched sensory information’ and then, ‘transmit the generated information over the internet through the Internet of Things (IoT)’, and also able for ‘generating alerts to caregivers’. The proposed design is also capable of providing audio & video feedback to calm down individuals with ASD.

**Results:** After testing, it is observed that 93% percent of the caregivers rated the proposed ACHI intervention on the scale of above average. The remarkable reduction in hyperactive states related triggering incidents in ASD has been found with the use of ACHI.

**Conclusion:** The present work and the proposed prototype can identify and control the sensory overload triggers in ASD and it can guide the caregiver or clinicians to optimize the responsible surrounding causes of explosive behavior in ASD and would help the individuals with ASD to become calm.

## 1. Introduction

The report presented by Autism and Developmental Disabilities Monitoring (ADDM) Network in America reflected that Autism Spectrum Disorder was becoming a serious concern of many countries in the world (Baio et al., 2018). The clinical definition of ASD included various factors such as impairments in communication, lack of social skills, and inflexible behavioral (Diagnostic and Statistical Manual of Mental Disorders, 2013; Harms et al., 2010; Kanner, 1944, 1943; Khullar et al., 2017; Lozier et al., 2014; Nuske et al., 2013). Recent developments revealed that many people with ASD could have profound difficulty in the processing the everyday sensory information in ‘unfriendly environment’ and sensory hypersensitivity in ASD had been found as powerful discriminator between children with and without autism (Baranek et al., 1997; Brown and Dunn, 2002; O’Neill and Jones, 1997; Olof Dahlgren and Gillberg, 2004; Rimland and Edelson, 2005). Kientz and Dunn (1997) and Lord et al (1994) observed 42%–88%

incidents were only due to sensory processing in individuals with ASD individuals. Due to the sensory processing deficits, the intense effects were reflected in the life of an ASD and sometimes the senses of autistic children could reach in uncontrollable stage which leads their feelings of sensory inputs to become over or under-loaded (Ben-sasson et al., 2007; Kern et al., 2006; Lai et al., 2011; Leekam et al., 2007). From the active senses, any of the sense at any random time could become oversensitive or under-sensitive which lead to hyper, hypo or perception based sensitivity related behavior disorders which could further trigger to cause discomfort, stress, anxiety, tantrum, or meltdown in individuals with ASD (Gomes et al., 2004; Talay-Ongan and Wood, 2007) and these distressed triggers could also lead to self-injurious, aggressive and dangerous explosions of behavior (Critchley, 2002; Fitzpatrick et al., 2016; Merikangas et al., 2010; Perrin, 2011; Simonoff et al., 2008). A multisensory environment, named “Snoezelen”, was designed to understand & analyze the impact of sensory stimulation on disabled persons under different environmental conditions (Kaplan

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et al., 2006). Some causes of sensory inputs due to different surroundings could be found as ‘noisy or sharp sounds’, ‘bright or dark lights’, ‘warm or cold weather’, ‘sudden change in axis’, ‘strong smells’, ‘familiar or unfamiliar locations’, etc (Feldman et al., 2019; Ide et al., 2019; Lovaas et al., 1971; Schoen et al., 2014; Shabha, 2006). The identification of triggering event for sensory overload in ASD could be an important aspect to optimize the surrounding causes related to explosive behavior in ASD (Shabha, 2006).

To measure sensory responses, various manual methods, including rating scales and questionnaires were developed which could rate the level of distress due to sensory inputs or triggers (Brown and Dunn, 2002; Riederer et al., 2015). The manual techniques were able to identify only through written, verbal or non-verbal communication with ASD or their caregivers in a controlled environment. To provide effective therapy or medication, exact and real-time identification of sensory cause could be required, which was difficult to understand by manual methods (Ayres et al., 2013; Escobedo et al., 2012). Sochting et al used the force, touch and RGB-D sensors to measure functions of children with ASD in different test scenarios and sent the retrieved information to real-time remote devices for continuous monitoring and alerting system. Angelini et al (2016) developed some interactive plants which could be able to perform auditory interaction and provide encouraging auditory feedback to assist the sensory skills of ASD. With the advancement in therapeutic approaches, Azzi et al (2016) developed a robot for multisensory therapy by adding music into the learning environment and observing the body movements and emotional gestures. Tang et al (2014) developed a wearable tactile sleeve to sense the virtual experiences in hypersensitive ASD’s of being touched by a human. It was observed that ASD children could be affected with sleeping disorder due to the cause of hypersensitivity and to tackle this deficiency, Biswas et al (2018) designed assistive sleeping bag which was based on wearable technology to calm the individuals with ASDs with deep touch feeling by embedding “body movement detection sensor” and “vibrating motor” along with sleeping bag. The internet-connected smart assistive devices had also shown their potential by reducing the dependency on dimensions for monitoring system (AngelSense, 2019; Trackimo, 2019). It was also proved that the fabrication of sensors for the physiological measurements could be integrated with different devices to respond efficiently (D’sa et al., 2019). Dueñas et al (2019) analyzed the impact of iPad based joint video modeling on scripted and unscripted verbalizations and scripted and unscripted play actions of children with ASD to understand the interaction behavior during pretend plays in an inclusive early age classrooms and suggested that the video modeling could be an effective way to replace adult facilitated interactions between children with ASD. Schmidt et al (2019) designed and tested Spherical video-based virtual reality (SVVR) mobile app which included reviews regarding user experience, relevance, usability of application & utilization feasibility for ASD individuals and found an overall positive outcome. Pérez-Fuster et al (2019) compared the impact of digital mediated intervention such as tablet controlled lightning system with paper based traditional systems for enhancing ASD individuals on the basis of daily living skills such as washing dishes & doing laundry and the significant improvement was observed in social behavior of ASD participants with reduced educator effort time. Sadeghi and Pouretemad (2019) proposed a parent training intervention which included development of emotional bond and bilateral interactions between individuals with ASD and their parents to avoid unusual activities and with time duration of two months, it was observed through EEG that the related repetitive behavior/ social communication was improved through proposed intervention.

The present work was aimed to design and analyze an assistive technology which could be able to understand, record, analyze and feedback according to surrounding environmental sensory input and also act as an electronic toy or bag companion which might not be restricted within wired boundaries and could be able to perform in real-



Fig. 1. Different Toy Bag Images for Intervention ACHI.

**Table 1**  
Demographic Characteristics of Participants.

	ASD	TD
Number of Children	10	5
Sex Ratio	8 : 2 (Male : Female)	2 : 3 (Male : Female)
Mean Age (in year)	~11.8 (8-19 years)	13.8 (10-15 years)

**Table 2**  
Working Algorithm of Intervention ACHI.

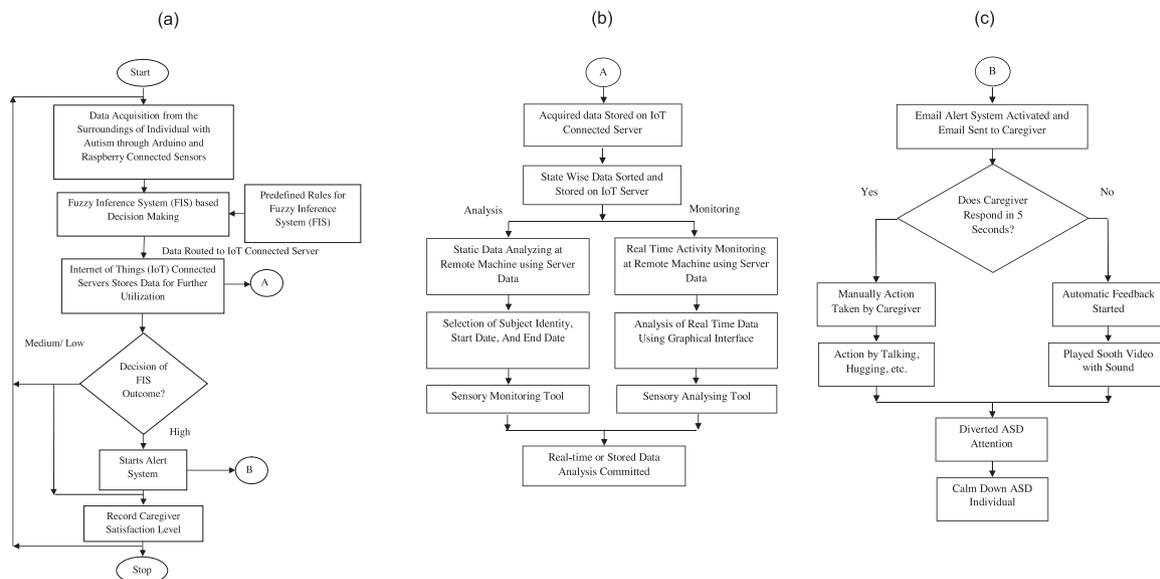
Algorithm
Step 1. The IoT based Assistive Companion for Hypersensitive Individuals (ACHI) Toy Bag carried along with ASD.
Step 2. Start data acquisition from the surroundings of an individual with autism through sensors connected with Arduino and Raspberry Pi.
Step 3 Decision making by Fuzzy Inference System (FIS) for the acquired data on the basis of predefined rules.
Step 4. Data (Sensory data & FIS decision) routed to the Internet of Things (IoT) server for data storage and further processing.
Step 4.1. State-wise sorted data stored on IoT server. (The user can further move to Step 4.1.1 or Step 5)
Step 4.1.1. Analysis of static data or real-time activity monitoring can be conducted on a remote machine using data from IoT server.
Step 5. Check the decision outcome of FIS.
Step 6. Activate the email alert system and send an Email to the caregiver.
Step 7. If the caregiver responds in a minute and manual action taken by a caregiver for calming down the autistic, then continue with step 8, else continue with step 7.
Step 8. Automatically start the feedback system and play soothing video and sound for calming down the autistic.
Step 9. Record the caregiver level of satisfaction.

time. An IoT based real-time assistive companion for individuals with sensory processing difficulties or hypersensitivity in ASD was proposed in this present work. The working of this intervention was based on sensory information such as vision, auditory, smell, and tactile in the surrounding environment of ASD and further, the proposed prototype intervention ‘ACHI’ could be embedded within a companion toy, bag, box, etc. In the proposed prototype intervention ‘ACHI’, a toy bag with tying belts as a companion object was used as presented in Fig. 1.

## 2. Material and method

### 2.1. Ethics statement

During the design and implementation of this study, a number of ethical considerations were incorporated likewise informed written consent, right to withdraw for the participants from the study at any time; none of the participants had received any psychoactive medication and anonymity of participants.



**Fig. 2.** Overall Working Flow of Intervention ACHI. a) Working Flow of Intervention ACHI. b) Working Flow of Analysis System of Intervention ACHI. c) Working Flow of Alert System of Intervention ACHI.

## 2.2. Participants

The real-time testing of the proposed system was performed on voluntarily reported 10 ASD and 5 Typically Developed (TD) individuals with normal vision and corresponding caregivers. All the ASD children had met the criteria defined by Diagnostic & Statistical Manual of Mental Disorders-Fifth Edition ([Diagnostic and Statistical Manual of Mental Disorders, 2013](#)), Autism Diagnostic Interview-Revised (ADI-R) criteria ([Kim and Lord, 2012](#); [Lord et al., 1994](#); [Zander et al., 2015](#)). All the participants were dextral and had normal or corrected to normal vision. Before the data recording sessions, each participant was given training sessions to adapt to experimental settings. [Table 1](#) highlighted the demographic characteristics of participant individuals with ASD.

## 2.3. Proposed system flow

The proposed ACHI intervention was capable to perform the task of data acquisition from the surroundings of an individual with autism through the sensors connected with Arduino ([“Getting Started with Arduino and Genuino,” 2019](#)) and Raspberry Pi ([“DATASHEET Raspberry Pi Compute Module 3+ Raspberry Pi Compute Module 3+ Lite,” 2019](#)). Further, on the basis of acquired information from the surroundings of ASD individual and predefined fuzzy rules in the Fuzzy Inference System (FIS) algorithms (coded using Python programming language ([“Python 2.7.16 documentation,” 2019](#)) on Raspberry Pi), the next stage decision was taken by ACHI. The real-time acquired data and the FIS decision data were further transmitted to the Internet of Things (IoT) connected remote-server through Raspberry Pi operating on wireless network. The real-time sensor’s data and FIS decisions were stored, maintained and continuously monitored at the IoT server by the auto-alert system algorithms. If the analyzed outcome of FIS was found ‘High’ (Sensory overload Situation), then the alert system in the proposed ACHI intervention was initiated automatically. The automatic alert system was capable to raise and transmit *an alert* to the caregivers by E-mail regarding the occurrence of awkward situation (which was identified as ‘High’ by FIS system) related to the individuals with ASD. If in some cases, caregiver were not able to respond in time, then proposed ACHI intervention system switched to *automatic calm-down mode* in which auditory-video feedback was activated automatically to calm-down the individuals with ASD during such kind of uncomfortable situations. The main strength and interesting feature of the proposed

ACHI intervention was continuous real-time monitoring and analysis of the present & previously acquired sensory data of the ASD individuals through Computer/Mobile Application. Though this feature of ACHI, the caregivers were capable to monitor & understand the present situation of ASD individuals and could be able to analyze the present situation by comparing the previous happened situations. Further, the basic steps of the working algorithm of ACHI intervention were presented in [Table 2](#) and the overall working flow of ACHI was presented in [Fig. 2](#).

## 2.4. Proposed system implementation

The design interface of ACHI intervention contained three different layered structures as Data Acquisition & Decision Making Layer, Real-Time Monitoring & Analysis Layer and Alert & Feedback Layer to handle hyperactive situations in individuals with ASD. The layered structure of proposed real-time implementation was presented in [Fig. 3](#).

The proposed Internet-connected server was able to handle multiple threads in parallel to receive data from different data acquisition and decision-making devices as presented in [Fig. 4](#) where IoT server was connected with all defined service layers through independent HTTP connections. The IoT server for ACHI was equipped with Intel Core I5 Processor, 8 GB RAM, 1TB HDD, Fiber connected Internet with static IP address, Linux Ubuntu Operating System, the Python programming language along with other required packages and software. The IoT connected server was always open to receive data from the data acquisition and decision-making layer of the proposed system.

### 2.4.1. Data acquisition and decision making layer

The advancement in semiconductor technologies made the sensors working nearly as similar to the human senses. The various devices required for data acquisition in ACHI were as MQ series sensors for smell sensation during different gases, camera for visual sensations during different intensities of light, microphones for auditory sensations during different frequency and loudness, 3-dimensional accelerometer for accessing tactile during different positions. These sensors were arranged in such a manner that ACHI could be capable to acquire data directly from surrounding of ASD individuals. After analyzing the requirement of the ACHI intervention, the following sensors and micro-controllers presented in [Table 3](#) were used.

The proposed electronic hardware intervention for data acquisition

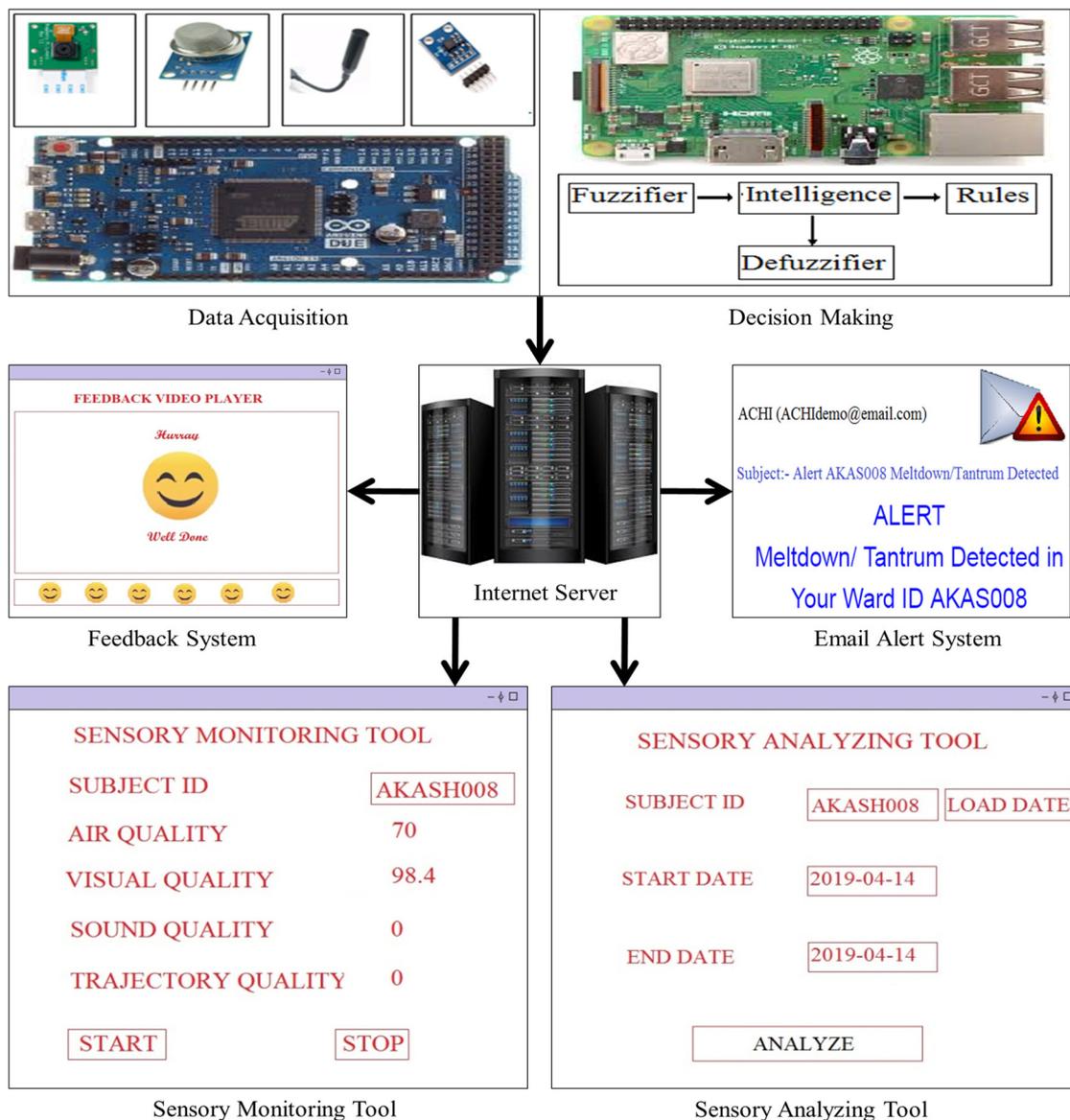


Fig. 3. Implementation Diagram of Intervention ACHI.

and decision making was shown in Fig. 5 which included Arduino Uno which could be able to acquire input from attached gas and 3-axis accelerometer sensors. Microphone, VGA camera, TFT Display, and Speaker were attached with the Raspberry Pi. The serial outcome of Arduino was forwarded to Raspberry Pi for further processing. All the attached electronic devices were getting power from 5-Volts Alkaline rechargeable battery. It was also identified that the ASD's were keenly interested to play with objects and toys (Charman et al., 1997; Ingersoll et al., 2003; Westeyn et al., 2012). By taking care of the interest of ASD individuals, the designed electronic circuits of proposed ACHI intervention was improvised in a toy bag. The proposed prototype intervention 'ACHI' was embedded in the shape of a companion toy bag with tying belts shown in Fig. 5. The real-time acquired data and the FIS decision data were further transmitted to the Internet of Things (IoT) connected remote-server through Raspberry Pi to store, maintain and continuously monitor by the auto-alert system.

The acquired data from various sensors & surroundings were further processed through the decision making layer where Fuzzy Inference System (FIS) was implemented. On the basis of acquired information from the surroundings of ASD individual and predefined fuzzy rules in the Fuzzy Inference System (FIS) algorithms, the next stage decision

was taken by ACHI. Further on the basis of acquired inputs as presented in Table 4 and predefined rules as shown in Table 5, the results were computed on the scale of 0 to 10.

#### 2.4.2. Real-time monitoring and analyzing layer

An interactive Graphical User Interface (GUI) was developed for real-time monitoring and analysis of the sensor values and its related FIS decisions as shown in Fig. 6(a) and (b). The interface shown in Fig. 6(a) represented the dedicated identity information of individuals with autism along with real-time sensor data of the surrounding of ASDs. The analysis interface presented in Fig. 6(b) was able to draw line graphs for the understanding of resultant trends of the present and previous happened situations/ activities for any particular subject ID with the start and end date. The GUI interface was specially designed for caregivers who could be easily able to monitor, understand and analyze the data of the particular individual with ASD.

#### 2.4.3. Feedback and alert layer

The Feedback & Alert layer was responsible for generating alert for caregivers and initializing feedback system to avoid awkward situations of sensory overload in individuals with ASD. ACHI system was able to

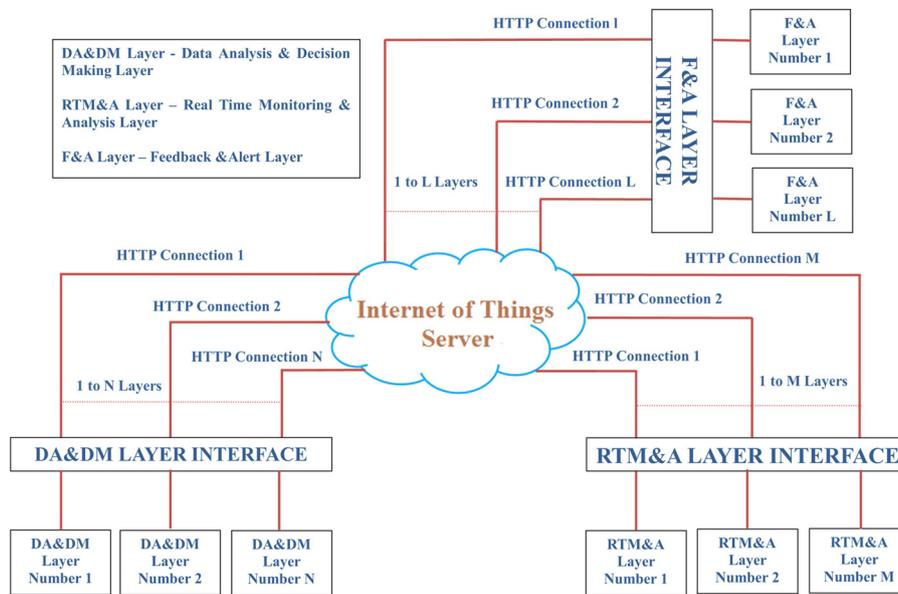


Fig. 4. Internet of Things (IoT) Connected with Other Service Layers in ACHI.

Table 3  
Sensors and Microcontrollers.

Sensor / Microcontroller	Purpose
Gas Sensor	To check air quality.
VGA Camera	To measure light intensity.
3-Axis Accelerometer	To identify the tactile movement.
Microphone	To measure sound loudness.
Arduino UNO	To fetch & control signal from sensors
Raspberry Pi supported with TFT Display Screen and Speaker	Applying decision making fuzzy logic, transmitting to the Internet-connected server, managing the alert system and feedback system.

Table 4  
Variable States for Fuzzy Mode.

S. No.	Variable	State
1	No Impact (Low)	0-5.0
2	Ignorable Impact (Medium)	2.5-7.5
3	Strong Impact (High)	5.0-10.0

send an e-mail message as an alert to the predefined caregiver’s internet-connected smart devices as presented in Fig. 6(c). When the outcome of FIS approached ‘High’, then the alert system of the ACHI intervention was initiated automatically and an E-mail to the corresponding caregiver could be sent which included the alert messages

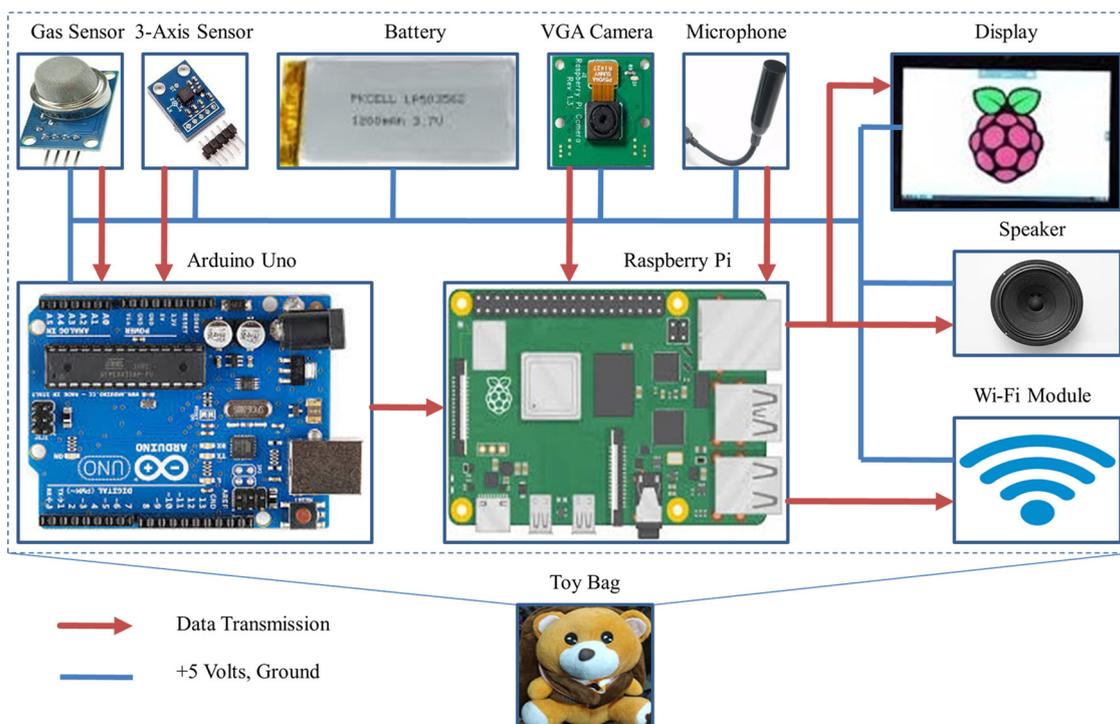
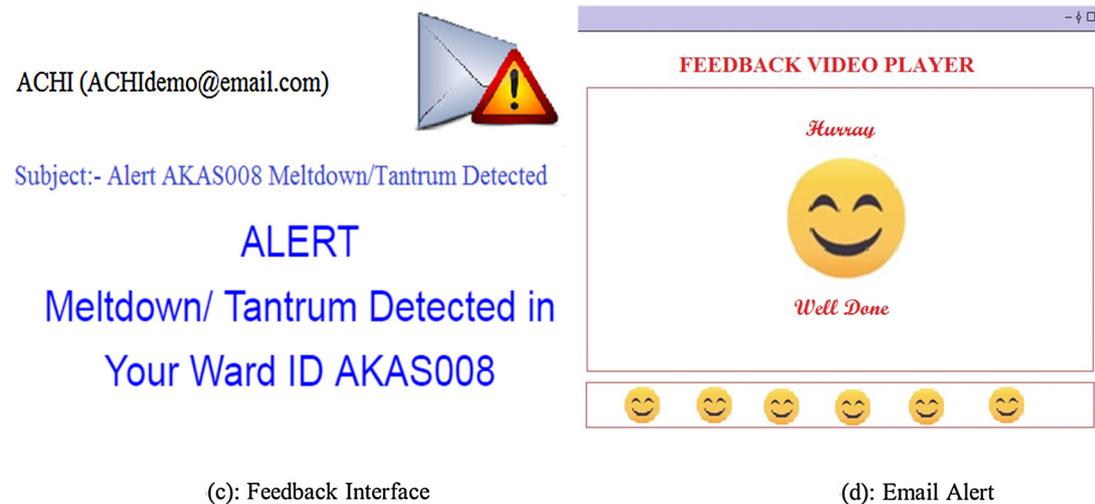
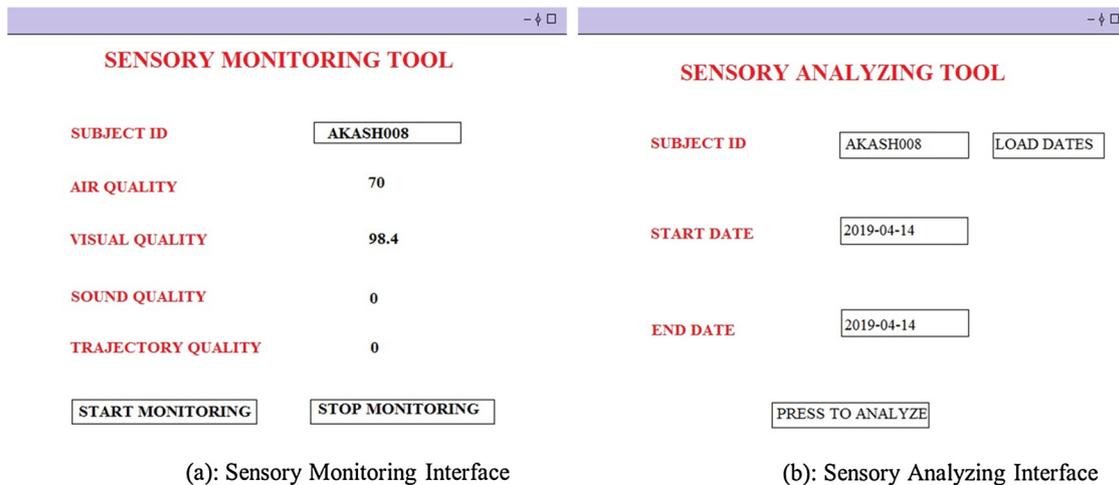


Fig. 5. Data Acquisition and Decision Making Layer for Intervention ACHI within Bag Shaped Companion Object.

**Table 5**  
Example Fuzzy Rules for Decision Making.

Rule	Decision
Smell is Low AND Sound is Low AND Axis is Low AND Vision is Middle	Low
Smell is High OR Sound is High OR Axis is High OR Vision is High	High
Smell is Middle AND Sound is Middle AND Axis is Middle AND Vision is Middle	Medium
Smell is Low AND Sound is Low AND Axis is Low AND Vision is Middle	Medium
Smell is Low AND Sound is Low AND Axis is Middle AND Vision is Middle	Medium
Smell is Low AND Sound is Middle AND Axis is Low AND Vision is Middle	Medium
Smell is Middle AND Sound is Low AND Axis is Low AND Vision is Middle	Medium
Smell is Low AND Sound is Low AND Axis is Low AND Vision is Middle	Medium



**Fig. 6.** Interactive Graphical Interfaces of ACHI.

**Table 6**  
Considered Decision of ACHI Fuzzy System on different Stimuli's.

Auditory Stimuli		Vision Stimuli		Tactile Stimuli		Smell Stimuli	
Auditory Type	Decision	Vision Type	Decision	Tactile Type	Decision	Smell Type	Decision
Vacuum Cleaner	HR	Sharp Light	HR	Seesaw	HR	Kitchen while Cooking	HR
Lawn Mover	HR	Darkness	HR	Stairs	MR	Garbage Area	HR
Normal Conversation	LR	Fluctuating Intensity	HR	Inclined Floor	MR	Dusty Area	HR
Emergency Vehicle Siren	HR	Day Light	LR	Plain Floor	LR	Community Park	MR
Personal Stereo	HR	Normal Room Light	LR	Escalators	MR	Closed Room	LR
Playing Songs	MR	Television or Other Displays	MR	Swings	HR	Perfumes	HR
Crowded Restaurant	MR			Spinning Around in Circles	HR		

HR is High Rated, \*MR is Middle Rated and \*LR is Low Rated.

**Table 7**  
Responses of ACHI Fuzzy Inference System (FIS) on a different combination of Sensory Stimuli's.

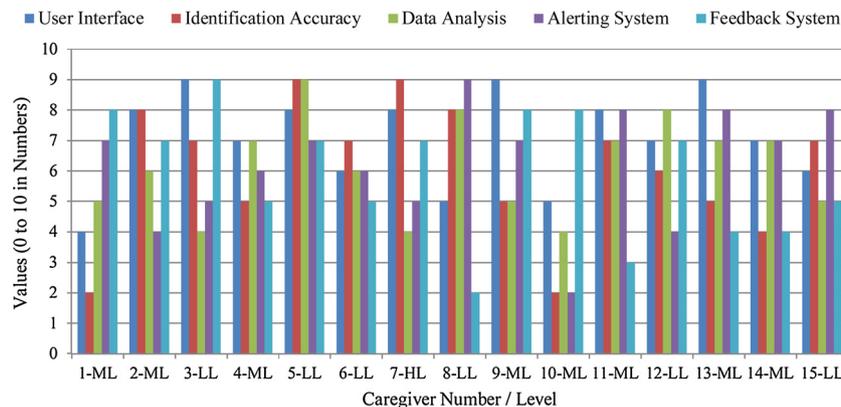
Stimuli Combination No.	Sensory Stimuli's Rating				Outcome Responses		
	Auditory	Vision	Tactile	Smell	Fuzzy Outcome	Alert Response	Feedback Response
1	LR	LR	LR	LR		No	No
2	HR	LR	LR	LR		Yes	Yes
3	LR	HR	LR	LR		Yes	Yes
4	LR	LR	HR	LR		Yes	Yes
5	LR	LR	LR	HR		Yes	Yes
6	LR	MR	MR	MR		No	No
7	MR	MR	MR	MR		No	No
8	LR	MR	LR	MR		No	No
9	HR	MR	MR	MR		Yes	Yes
10	LR	HR	HR	LR		Yes	Yes
11	MR	LR	HR	HR		Yes	Yes
12	HR	MR	MR	HR		Yes	Yes
13	HR	HR	HR	HR		Yes	Yes

\*HR is High Rated, \*MR is Middle Rated and \*LR is Low Rated.

**Table 8**  
Initial Responses of Caregivers with ACHI.

Caregiver Details			Rating Parameters (Rating scale is between 0-10)					
Caregiver No.	Caregiver Level	Group	User Interface	Identification Accuracy	Data Analysis	Alerting System	Feedback System	Overall
1	ML	ASD	4	2	5	7	8	5.2
2	ML	ASD	8	8	6	4	7	6.6
3	LL	ASD	9	7	4	5	9	6.6
4	ML	ASD	7	5	7	6	5	6
5	LL	ASD	8	9	9	7	7	8
6	LL	ASD	6	7	6	6	5	6.8
7	HL	ASD	8	9	4	5	7	6.8
8	LL	ASD	5	8	8	9	2	6.4
9	ML	ASD	9	5	5	7	8	6.8
10	ML	ASD	5	2	4	2	8	4
11	ML	TD	8	7	7	8	3	6.6
12	LL	TD	7	6	8	4	7	6.4
13	ML	TD	9	5	7	8	4	6.6
14	ML	TD	7	4	7	7	4	5.8
15	LL	TD	6	7	5	8	5	6.2
<b>Satisfaction Percentage (Above Average i.e. 5)</b>								93%

HL – Highly Literate about ASD, ML –Average Literate about ASD and LL- Less Literate about ASD.



**Fig. 7.** Caregiver Responses corresponding to related Individual Subjects for different Parameters and Overall Mean Value for Intervention ACHI.

**Table 9**  
Discriminant Analysis based on Initial Responses of Caregivers.

Domain	Caregiver Group	N	Mean	SD	t-Stat	p-value
User Interface	ASD	10	6.9	1.79	-0.563	0.58
	TD	5	7.4	1.14		
Identification Accuracy	ASD	10	6.2	2.62	0.318	0.75
	TD	5	5.8	1.3		
Recorded Data Analysis	ASD	10	5.8	1.75	-1.15	0.268
	TD	5	6.8	1.1		
Alerting System	ASD	10	5.8	1.93	-1.16	0.263
	TD	5	7	1.73		
Feedback System	ASD	10	6.6	2.07	1.90	0.079
	TD	5	4.6	1.52		
Overall System	ASD	10	6.26	2.01	0.058	0.955
	TD	5	6.32	1.62		

Significant value at  $p < 0.05$ .

**Table 10**  
Satisfaction Level of Caregiver for Without and With ACHI Alert System in Real-Time and Uncontrolled Environment.

Sr. No.	ASD Caregiver and Individual Details			Alert Satisfaction Outcome (0-10 Scale) by Caregiver	
	Caregiver Level	Age	Sex	Caregiver Level	
1	ML	13	M	4	8
2	ML	5	M	6	8.5
3	LL	6	M	2	7.5
4	ML	14	F	1	9
5	LL	15	M	4	6
6	LL	9	F	5.5	7
7	HL	6	M	3	5
8	LL	13	M	3	8
9	ML	11	M	0	9
10	ML	8	F	5	5
Satisfaction Percentage (Above Average i.e. 5)				20% out of 10 Caregivers	80% out of 10 Caregivers

regarding occurrence of awkward situation related to the individuals with ASD. In some cases, when the caregivers were not available near to the corresponding ASD individual or were not able to respond in time, then proposed ACHI intervention system switched to *automatic calm-down mode*, in which automatic auditory-video feedback system was activated. The automatic auditory-video feedback system was able to play some favorite audio/ video clips on the attached screen/speakers to calm-down the corresponding individuals with ASD during uncomfortable situations of sensory overload as presented in Fig. 6(d).

**Table 11**  
Satisfaction Level of Caregiver for Without and With ACHI Feedback System in Real-Time and Uncontrolled Environment.

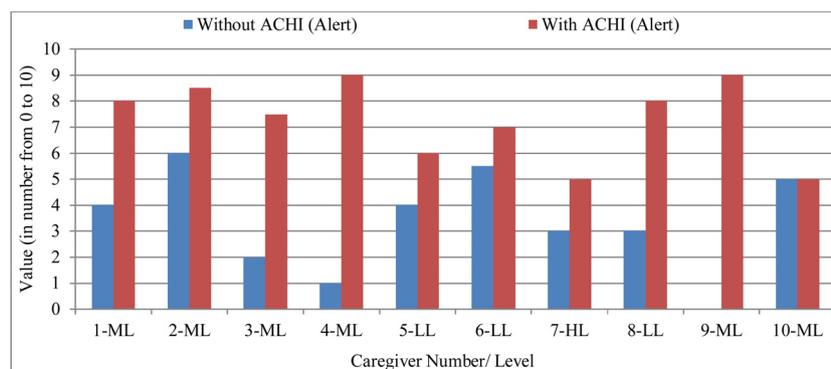
Sr.	ASD Caregiver and Individual Details			Feedback Satisfaction Outcome (0-10 Scale) by Caregiver	
	Caregiver Level	Age	Sex	Without ACHI (Feedback)	With ACHI (Feedback)
1	ML	13	M	3	8
2	ML	5	M	2	7
3	LL	6	M	6	6
4	ML	14	F	0	8
5	LL	15	M	1	6
6	LL	9	F	2	7
7	HL	6	M	4	8
8	LL	13	M	5.5	9
9	ML	11	M	0	8
10	ML	8	F	1	4
Satisfaction Percentage (Above Average i.e. 5)				20% out of 10 Caregivers	95% out of 10 Caregivers

### 3. Evaluation results of ACHI

The performance of the proposed ACHI intervention was evaluated through three different stages such as initial testing under controlled environment, then working & performance of ACHI was validated with corresponding caregivers of ASD and TD subjects under controlled environment and at the last stage, the ACHI intervention was tested and validated with ASD individuals in real-time/uncontrolled environment.

#### 3.1. Initial testing of ACHI with different stimuli's in controlled environment

The performance of the proposed ACHI intervention was initially tested with different stimuli's in a controlled environment. The controlled environment was created by providing different user-generated stimuli's which included High Rated (HR), Medium Rated (MR) or Low Rated (LR) data/ signal related to audio, visual, tactile and smell as presented in Table 6 (Kern et al., 2006; Leekam et al., 2011, 2007; Ryan, 2010; Talay-Ongan and Wood, 2007). The ACHI intervention responded accurately in all the test cases of abnormal conditions of sound, light, axis or smell such as the sound of vacuum cleaner, fluctuation in light, darkness, moving on the inclined floor, garbage area, kitchen while cooking, etc. Further, different combination of sensory inputs (HR, MR & LR) and Fuzzy Inference System (FIS) decision output of ACHI were defined and presented in Table 7. The different combination of the tested sensory inputs could generate fuzzy outcome through FIS system on the basis of predefined rules. The fuzzy outcomes were responsible for activating the automatic alert and feedback response system.



**Fig. 8.** Satisfaction Level of Caregiver for Without and With ACHI Alert System in Real-Time and Uncontrolled Environment.

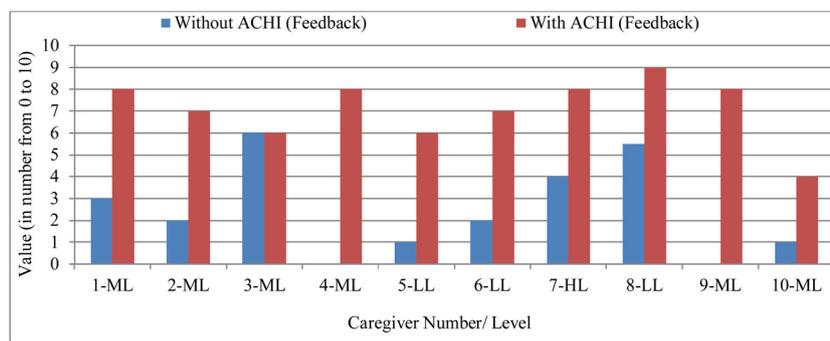


Fig. 9. Satisfaction Level of Caregiver for Without and With ACHI Feedback System in Real Time and Uncontrolled Environment.

Table 12

Discriminant Analysis based on Uncontrolled and Real-Time Environment Results.

Domain	Group	N	Mean	SD	t-Stat	p-value
Alerting System	With ACHI (Alert)	10	7.3	1.51	-4.27	0.002
	Without Alert	10	3.3	1.88		
Feedback System	With (ACHI) Feedback	10	7.1	1.44	-7.23	0.000048
	Without Feedback	10	2.3	1.88		

The \*Significant value of  $p < 0.05$  is in between - 2.160 to + 2.160.

### 3.2. Testing of ACHI in controlled environment

ACHI was provided as an intervention to two different categories of participants in which one belongs to ASD and other was TD and the tested environment was controlled with different stimuli. For each participated subject (10 ASD & 5 TD), one caregiver with different level of literacy about ASD, such as Highly Literate about ASD (HL), Average Literate about ASD (ML) and Less Literate about ASD (LL) was provided. Since the validation of the proposed ACHI intervention could be evaluated on the basis of the responses of the caregivers about ACHI, so the different level of literacy about ASD of caregiver was chosen in such a way that the validation of ACHI could be unbiased. The performance was analyzed & rated on the basis of the following five parameters such as User Interface, Identification Accuracy, Data Analysis, Alerting System, and Feedback System. Each parameter was rated on a scale of 0 to 10 and the overall rating of ACHI was the averaged value of all the parametric ratings as presented in Table 8 and Fig. 7. Irrespective of the literacy level about ASD of caregivers, it was observed from the results in Table 8 & Fig. 7 that most of the caregivers had recorded mean overall value as above average such as greater than 5 on the scale of 0-10. 93% caregivers out of the participated 15 caregivers had rated the intervention ACHI as above average. The caregivers were also excited to the main feature of ACHI that with the help of this device, irrespective of ASD & TD category, each caregiver was aware of actual situation faced by ASD individuals.

#### 3.2.1. Discriminant analysis based on initial responses of caregivers

The discriminant analysis was performed on the collected responses

Table 13

Comparison Table for proposed ACHI and other Interventions.

Intervention and Reference	Data Analysis System	Remote Monitoring	Feedback System	Alerting System	Companion
<b>Proposed Intervention ACHI</b>	Yes	Yes	Yes	Yes	Movable, Both Indoor and Outdoor
AngelSense Wristband (*AngelSense, 2019)	No	Yes	No	Yes	Movable, Both Indoor and Outdoor
Multi-Sensory Augmented Plants (Angelini et al., 2016)	No	No	Yes	No	Not Movable
(Söchting et al., 2015)	Yes	Yes	Yes	No	Not Movable
Robot (Azzi et al., 2016)	No	Yes	Yes	No	Indoor
Robot (Robins and Dautenhahn, 2014)	No	Yes	Yes	No	Indoor

of the caregivers as presented in Table 9. The mean scores of the ASD group caregiver were 6.26 which could be found nearly similar to the TD group caregiver with mean scores of 6.32 at significant value  $p < 0.05$ . It was observed from the statistical analysis of responses that the proposed ACHI had equal potential for both ASD and TD groups under a controlled environment.

### 3.3. Testing of ACHI in real-time / uncontrolled environment

The performance of ACHI was tested and analyzed with ASD participants in real-time/uncontrolled environment with different real-time stimuli along with their caregivers. In the real-time testing process, 10 ASD subjects with normal vision and auditory capabilities along with their respective caregivers had participated. The uncontrolled environment was referred to as day-to-day life in normal & regular environment in which there was no control on the generation of sound, visual, tactile and smell related stimuli's. One caregiver with different literacy level (HL, ML & LL) was provided to each participant to make validation unbiased.

The performance of ACHI was evaluated on the basis of the alert system with 10 participating ASD caregivers and the satisfaction level was recorded on the scale of 0 to 10 as presented in Table 10 and Fig. 8. It was found from the results obtained in Table 10 and Fig. 8 that the remarkable improvement in the satisfaction level of the ACHI alert system with the mean value of 7.3 was achieved as compared to mean value 3.3 of without the use of ACHI intervention. Further, the satisfaction level of feedback system of ACHI was also evaluated and recorded on the scale of 0 to 10 as presented in Table 11 and Fig. 9. The significant improvement in the satisfaction level of caregiver was noticed with the utilization of ACHI intervention since the mean value of satisfaction level with the use of ACHI was increased to 7.1 from 2.3, which was mean value of the satisfaction level of caregiver without the use of ACHI. It was found that 80% and 95% of participated caregivers were satisfied with the utilization of ACHI alert and the feedback system respectively and responded positively above average (greater than 5 on the scale of 1 to 10). In contrast, only 20% caregivers were satisfied by scoring above average (greater than 5 on the scale of 1 to 10) without the use of ACHI alert and feedback system. The significant improvement in satisfaction level of caregivers supported the utilization of ACHI intervention for individuals with ASD.

### 3.3.1. Discriminant analysis based on real-time results

The discriminant analysis was performed on the collected responses of the caregivers for two domains such as Alerting system & Feedback system under two groups 'with ACHI' & 'without ACHI' as presented in Table 12. For alerting system, the improved mean score of "with alert" group was found to be 7.3 as compared to 'without alert' group, where mean score was 3.3, at significant value  $p < 0.05$ . Similarly, the mean score of 'with feedback' group was improved from 2.3 to 7.1 at significant value  $p < 0.05$ . Statistically, it was validated that ACHI with alert and feedback system had performed better as compared to without ACHI group for both ASD and TD subjects in real-time/ uncontrolled environment.

## 4. Discussion

It was observed from the investigation results that ACHI could work efficiently in the initial testing phase and also in controlled & real-time/uncontrolled environment without any losses. The tested results of ACHI performance revealed that around 93% of the participated caregivers were satisfied with the features such as real-time monitoring, analysis, alert & feedback, provided by ACHI and the results were supported by the statistical analysis as presented in Table 9 and Table 12. It was found that ACHI worked impartially for both ASD & TD participants with mean scores of 6.26 & 6.32 respectively. The dramatic increase in the satisfaction rating of caregivers for alert system from 3.3 to 7.3 and feedback system from 2.3 to 7.1 of ACHI was observed on the scale of 0 to 10, which indicated more effort rate to calm down individuals with ASD during meltdown/tantrum or other hyperactive incidents.

The highlighting feature of the proposed design of ACHI was that the monitoring reports of each individual could be stored at IoT connected server from where the corresponding caregiver was able to fetch & analyze the previous report and compare with present report of ASD individuals to identify the actual cause responsible for raising meltdown/tantrum and hyperactive behavior. The identified actual cause could be one of the senses tested in the present work, and then it could be possible for the caregivers/clinicians to provide the specific treatment according to the identified cause/sense to ASD individuals for making them calm during the hyperactive state. The uniqueness of ACHI intervention could also be proved through the comparison with other existing interventions as presented in Table 13.

## 5. Conclusion

Since individuals with ASDs were oversensitive to surrounding sensory inputs and most caregivers or practitioners demand real-time monitoring of the sensory inputs of their child, the proposed ACHI intervention was designed to cope up the problems faced with manual monitoring & feedback systems. The highlighting features of the proposed ACHI intervention included identification of the actual cause of the meltdown/tantrum or hyperactive behavior and significant utilization of ACHI for individuals with ASD and typically developed children. The performance results of ACHI were validated and unique features were also compared with other existing intervention and it was found that proposed ACHI intervention could be efficiently used as companion with ASD individuals. The use of interactive ACHI as effective toy companions could analyze and diminish the aggressive, hyperactive, or meltdown related behavior of ASD in safe and economical manner.

In future, the proposed design of ACHI can also be tested for other sensory-related conditions in disorders such as Attention Deficit Hyper Active Disorder (ADHD), Sensory Processing Disorder (SPD), etc and further, the work can also be extended to control physical environment by embedding advanced technologies and algorithms such as Machine Learning, Deep Learning, Virtual Reality, Big Data, Advanced Microcontrollers, etc.

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We (authors) declare that we have no conflict of interest for manuscript entitled "IoT based Assistive Companion for Hyper-Sensitive Individuals (ACHI) with Autism Spectrum Disorder".

## Declaration of Competing Interest

We (authors) declare that we have no conflict of interest for manuscript entitled "IoT based Assistive Companion for Hyper-Sensitive Individuals (ACHI) with Autism Spectrum Disorder".

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