A Review of Wearable Tracking and Emotional Monitoring Solutions for Individuals with Autism and Intellectual Disability

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***Abstract*—Autism Spectrum Disorder (ASD) and Intellectual Disabilities (ID) affect an increasing proportion of today's population. Individuals with ASD/ID exhibit frequent forms of challenging behaviours such aggression and wandering off without warning. Wandering or elopement is common among such population and poses a great risk to the individuals and causes significant stress to their caregivers. Concurrent with wandering is sometimes anxiety and stress which may lead to disruptive challenging behaviours emerging from their varying internal emotional states and hyper-sensory to their surroundings. Caregivers and/or family members do need to keep track of such vulnerable population especially the ones with more severe autism/intellectual disabilities. The use of location tracking and emotional monitoring solutions can assist caregivers and family members by complementing their behavioural monitoring and intervention approaches. This paper reviews existing location tracking and physiological monitoring wearable products suited for this population. This can help caregivers and family members select suitable device for the person of concern taking account his/her unique user needs.**

Keywords-autism; assistive technology, emotional monitoring, intellectual disabilities, patient localisation, wearable sensors.

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterised by deficits in reciprocal social interactions and communication skills, accompanied by restrictive and repetitive behaviours. Intellectual disability (ID), on the other hand, can be characterised by deficits in intelligence and adaptive behaviour that is at least two standard deviations below the mean of the general population. Individuals with ASD/ID exhibit frequent forms of challenging behaviours that reduce their well-being and quality of life. Individuals with ASD are at higher risk of developing challenging behaviours compared to the general population [1].

One common kind of challenging behaviours is wandering and elopement. A recent research study reported that about half of children with autism spectrum disorder are prone to wandering [2] which can be very stressful for parents, particularly so for parents caring for children with developmental disorders, where the child's ability to communicate with strangers may be impaired. Also, it has been found that more than a quarter of children with developmental disabilities wander away from safe environments [3]. Further, researchers found that nearly a third of reported ASD missing person cases related to wandering/elopement from 2011 to 2016 in the United States ended in death or required medical attention [4].

Therefore, a mechanism that allowed parents and carers to track the locations of those individuals could have significant benefits and reduce risk. Secondly, such a device could potentially be used to monitor physiological signals which may correlate with internal emotional states, such as high levels of stress. This data may predict episodes of wandering/elopement, and could be used to ensure the intervention to reduce stress, or to identify their location in case being lost.

Since external challenging behaviour such as wandering is accompanied with anxiety issues and varying emotions, it will be very useful for caregivers to monitor the internal physiological and emotional states of the care-receiver to help them understand what such individuals are experiencing in a real-time fashion. Building on such physiological information, caregiver can take necessary actions to help the individual calm down, in case he/she is experiencing stress, for example. Also, having a wearable device may help some individuals with autism spectrum disorder to increase their self-awareness of their internal emotional state and anxiety levels so that they can follow certain behavioural techniques and coping strategies to help them self-regulate their emotions [5]. This could be particularly useful for clients with comorbid alexithymia.

This paper reviews commercial devices that can track location and physiological signals, with the potential for application to individuals with ASD/ID. Specifically, it presents the existing commercial solutions, compares their features and associated sensors, and comments on their effectiveness and open challenges for this application.

II. ASD/ID AND THEIR UNIQUE NEEDS

ASD and ID are a broad spectrum of disorders ranging from mild to profound intellectual disabilities. Individuals with these conditions experience a full range of emotional states, which can be triggered by a variety of environmental and sensory cues, and internal experiences. For example, escalated levels of anxiety can potentially lead to what is called Challenging Behaviour. Challenging behaviour is defined as a culturally abnormal behaviour(s) of such an

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intensity, frequency or duration that the physical safety of the person or others is likely to be placed in serious jeopardy [6]. Challenging behaviour include wandering/elopement, aggression, self-injury, property destruction, and tantrums. Prevalence rates as high as 94% have been reported for challenging behaviour in children with ASD [7]. Therefore, those individuals have unique needs. The widespread use of wearable technology offers an opportunity to help caregivers monitor and support such individuals. The use of wearable devices embedding sensing modalities such as location tracking and physiological sensing can offer a promising support for children and adults with ASD/ID who engage in challenging behaviour [5].

III. Related Work

A number of reviews of relevant literature have been published. For example, S. Majumder et al [8] conducted a review study on sensors used for remote monitoring for general population. The authors compared various physiological and activity monitoring solutions aimed for the elderly population. Specifically, separate comparative studies for wearable monitoring devices of cardiovascular system, body temperature, oxygen level parameters, and activity trackers were presented. Another work focused on the wearable technology from clinical perspective such as wellness, safety, and home rehabilitation for older adults and individuals with chronic conditions was conducted by S. Patel et al [9].

More recently, there has been a focus of reviews on the application of wearable technology to specific populations which bring unique design and function needs. This is because some populations have different design and wearability requirements [5]. Example of such users are the ASD/ID population. According to a survey conducted by S. H. Koo et al [5], parents of individuals with ASD were particularly interested in being able to monitor their son or daughter's physiological signals to understand anxiety levels and other emotions (72%). J. Cabibihan et al [10] surveyed the research literatures on different sensing technologies that are suitable for screening and intervention for ASD. Those sensing technologies were categorised into eye trackers, movement trackers, physiological activity monitors, tactile sensors, vocal prosody and speech detectors, and sleep quality assessment devices. The benefits and effectiveness of those devices in supporting the treatment of some symptoms of autistic individuals as well as their limitations were assessed.

According to S. H. Koo et al [5], tracking the individual's activity or location is the third most requested information by parents of individuals with ASD after the emotional state and aiding of multi-step tasks. Also, M. T. K. Tsun et al conducted a review study on tracking devices in ASD population [11]. The authors investigated potential future assistive tracking solutions for children with cognitive disabilities. Various localisation techniques have been considered such as radio frequency, inertial measurement units, and Global Positioning System which can be utilised for indoor and outdoor localisation.

As it can be seen, existing review papers either: study wearable devices for general or elderly population [8], [9] focuses on the research prototypes designed for individuals with ASD or ID [10], or target the devices offering one functionality such as the work by M. T. K. Tsun et al [11]. To the author's best knowledge, no consideration has been given to commercial solutions that enable emotional monitoring as well as location tracking devices. This paper focuses on devices that offer those two functions.

IV. Technologies and Sensing Signals Used

Building on the urgent need found in previous section, this section discusses the technologies and sensors used in the following subsections.

A. Location Tracking Technologies

Location tracking solutions use different technologies based on the required distance and the environment. For example, indoor monitoring devices can use accelerometer sensors, infrared tags, Bluetooth or WiFi wireless network available inside the building, or use a combination of technologies for more accurate tracking. Solutions targeted for outdoor location monitoring mostly use Global Positioning System (GPS) or cellular network service (such as GSM or third generation mobile communications).

B. Physiological Sensing Technologies for Emotional Monitoring

Emotional assessment for individuals with autism spectrum disorder and intellectual disabilities can provide insights into the function of the challenging behaviour and supplement costly traditional observational approaches. Physiological monitoring is found useful to assess the varying emotional levels as it can be measured noninvasively [12]. Typical physiological signals used include: Heart Rate (HR), Heart Rate Variability (HRV), Cortisol Level, Respiration Rate (RR), Electrodermal Activity (EDA), Skin Temperature (ST), and Electromyography (EMG). Other potential technologies may be useful to apply, such as eye tracking, using ElectroEncephaloGram (EEG) or brain signals but, due to the intrusive nature of the devices required for the individual with ASD/ID, they will be excluded in this study. It should be noted that various emotional states can be inferred from the measured values such as: low mood, high stress levels, agitation, excitement, and aggression.

V. Review of Existing Tracking and Monitoring Products

While the market is abundant with various products that are targeted for tracking and health monitoring of general population, there is a set of products that are designed specifically for individuals with autism and/or intellectual disabilities or can be adopted for this population. In this section, we provide a review of existing solutions listed for each category. The criteria for selection were: (1) devices that are designed specifically for individuals with ASD or ID, then (2) devices designed for general population but can

be adopted for ASD or ID population in terms of offering the functionality that delivers the service. Selected devices are consumer electronic device or medically approved ones. If a device is clinically validated, it is noted in the tables.

This section gives an overview of the devices/solutions that can be used for monitoring the individuals with ASD/ID. Such solutions can be categorised into two groups: (a) solutions for tracking the location of the person of concern, and (b) solutions for monitoring the internal emotional state or physiological state identification. Those solutions will be reviewed in the following two subsections:

A. Location Tracking Solutions

TABLE I. lists examples of related products. The following products are either commercially available in the market or still under development. For instance, Amber Alert GPS [13] is a tracking device that can be fitted in the backpack of the child or can be worn with a lanyard around the neck and it uses 3G cellular network to track the individual. Also, Angle Sense Location Tracker [26] is a GPS device that can be inserted into a sleeve that can be put in the pocket or in the interior of the clothing. Another device called Trackimo [21], from Trackimo, uses five tracking modules: GPS, GPS-A, GSM, Wi-Fi and Bluetooth suitable for both indoor and outdoor tracking. Examples of other devices that can be attached to the person's clothing are: Pocket Finder [27], Trax GPS Tracker [28], Securus eZoom and SPOT 3 Satellite GPS Messenger [18], Yepzon One [19], My Buddy Tag [20].

TABLE I. LOCATION TRACKING PRODUCTS

Product	Device Type	Wireless Technology and Range
Amber Alert GPS [13]	wristband	GPS for outdoor tracking
Angle Sense Location Tracker [14]	Wristband	Indoor tracking using Wi-Fi
Pocket Finder [15]	Attachable device	GPS/AGPS, 3G Cell ID for outdoor location and Wi-Fi Touch for indoor locations
Trax GPS Tracker [16]	Attachable device with clips	Location tracking using GPS, Beidou, and QZSS
Securus eZoom [17]	pocket-sized device	GPS for outdoor tracking
SPOT 3 Satellite GPS Messenger [18]	pocket-sized device	GPS for outdoor tracking
Yepzon One [19]	pocket-sized device	GSM network, GPS for outdoor and Bluetooth for near distances
My Buddy Tag [20]	Tag on wristband	Bluetooth for near distances
Trackimo GPS Track Watch [21]	Watch	GPS for outdoor, Wi-Fi for indoor tracking, and Bluetooth for short range tracking
FiLIP Solution [22]	wristband	Location tracking using GPS, GSM & WiFi
BeLuvv Guardian [23]	Bracelet or necklace	Bluetooth for near distances
Polar Team Pro [24]	T- Shirt	GPS for outdoor
D-Shirt [25]	T- Shirt	GPS for outdoor, altitude and route

A recent acceptability study was conducted using questionnaires with individuals with autism spectrum disorder and their parents to see what types of devices they prefer to use. Accessories such as watches/wristband and bracelets have been found to be the most preferred wearable technology types [5]. Therefore, several companies have developed wristband/watch type devices such as FiLIP [29], for example, that can track the location of children both indoors and outdoors using GPS, GSM and WiFi with the ability to contact the caregiver in case of emergency. Another device is BeLuvv Guardian suited for short range tracking [23] that uses Bluetooth technology. Another product called, Trackimo GPS Track Watch, uses three ranges for tracking: GPS for outdoor, Wi-Fi for indoor tracking, and Bluetooth for short range tracking.

Smart clothing offers a seamless experience and thus can be used to track individuals with sensory sensitivities, who may not tolerate devices such as wristbands or watches. Furthermore, garments, such as t-shirts, have been found the second most preferred item for individuals with autism spectrum disorder [5]. Therefore, t-shirts and vests equipped with location trackers can be used to track those individuals by their parents or caregivers. Although most t-shirts with location tracking on the market are aimed for athletes, some may be adopted for individuals with autism spectrum disorder/intellectual disabilities. An example of those is Polar Team Pro that offers location and motion tracking sensors in addition to heart rate monitor [24]. Another one but still under development called D-Shirt by Cityzen Sciences which is also planned to measure heart rate, route, speed, and altitude [25].

B. Emotional State Monitoring Solutions

The list of examples of physiological and/or emotional monitoring devices is presented in TABLE II. Wristbands and watches have also been the mainstream wearable device technology for physiological monitoring and emotional assessment. A brief description of the solutions/products is presented in the following paragraphs.

Simple consumer devices like Fitbit 2 can collect some physiological data such as heart rate. However, there are concerns pertaining to the reliability of such devices and their lack of capability to provide clinical data [30]. A more reliable solution which can provide more comprehensive physiological data is E4 Wristband from Empatica, Inc. which measures heart rate, heart rate variability, electrodermal activity, and skin temperature. However, this device can only collect raw physiological signals without

providing insights or assessment of the internal emotional state.

TABLE II. PHYSIOLOGICAL AND EMOTIONAL MONITORING PRODUCTS

Product/Forthcoming Device	Purpose	Device Form Factor	Sensors/Parameters	Usefulness/Clinical Validation	Shortcomings
E4 wristband, Empatica Inc. [31]	Collecting physiological and movement data only	Wristband	HR, HRV, EDA, ST, Acceleration	Medical Device class 2a (EU), FCC CFR 47 Part 15b IC (Industry Canada)	- Obtrusive (may not be tolerable by individuals with severe to profound ID)
TouchPoints wristband (*Forthcoming*), TouchPoints, Inc. [32]	Stress and anxiety relief	Wristband	Bi-lateral alternating stimulation –tactile (BLAST)	Patent-pending neuroscientific technology to relieve stress	Obtrusive (may not be tolerable by individuals with severe to profound ID)
MyFeel wristband, Sentio Solutions Inc. [33]	Recognising emotions	Wristband	HR, EDA, Skin temperature (ST),	Preliminary study showed usefulness on 150 subjects. However, no clinical validation	Obtrusive (may not be tolerable by individuals with severe to profound ID)
Reveal (*Forthcoming)*, Awake Labs [34]	Monitoring stress and anxiety	Wristband	HR, EDA, ST	Clinical trials being conducted but not clinically validated yet.	-Initial prototype, not validated, only for anxiety. - May not be suitable by individuals with severe to profound ID
BioHarness 3.0, Zypher, Inc. [35]	Physiological and activity data collection	Chest strap	HR, HRV, EDA, body temperature, RR, activity, posture, location	Clinical HR measurements [36] but not to clinical HRV [37].	Obtrusive (may not be tolerable by individuals with severe to profound ID)
Equivital Sensor Belt [38]	Physiological and activity data collection	Chest Belt	ECG; HR, HRV, Respiratory rate (RR), EDA, ST, accelerometer, Body position	EQ02 can accurately measure ECG and HRV, its accuracy and precision is highly dependent on artifact content [39]	Obtrusive (may not be tolerable by individuals with severe to profound ID)
Zephyr belt, Medtronic, Inc. [40]	Sports health monitoring	Belt	HR, HRV, RR	Suitable for consumer electronics but no clinical validation	Obtrusive (may not be tolerable by individuals with severe to profound ID)
Hexoskin Smart Shirt, Hexoskin Inc. [41]	Physiological and activity data collection and monitoring quality of sleep	Shirt	HR, HRV, Heart rate recovery, Respiration rate (RR) and volume, Acceleration and power	Clinical validated to obtain precise ECG cardiac monitoring for long-term monitoring [42]	Does not support real-time streaming or processing, but may be suited for monitoring of certain individuals with ASD/ID who cannot tolerate wristband
Polar Team Pro Shirt, Polar Electro Oy [24]	Sports health monitoring	Shirt	HR, location and motion tracking	Not clinically validated	Could be used for individuals with ASD/ID who can tolerate wearing the shirt
AIO Sleeve, Komodo Technologies [43]	Physiological, activity data collection and monitoring quality of sleep	Sleeve	ECG, HR, HRV, accelerometer	Not clinically validated	Does not support real-time streaming/processing (may be suited for monitoring of certain individuals with ASD/ID who cannot tolerate wristband)

More advanced solutions have been developed that use emotional identification algorithms to make meaningful information out of such data. For example, MyFeel wristband, from Sentio Solutions Inc [33], uses proprietary algorithms to process the data where it collects heart rate, electrodermal activity and skin temperature.

Another device that is still under development and targeted for the population with autism spectrum disorder called Reveal, from Awake Labs [34]. This device collects heart rate, electrodermal activity and skin temperature data to assess anxiety level of the individual and can notify the

caregiver when anxiety levels start to rise by applying data analytics techniques to make smart clinical decisions.

Another more advanced solution called TouchPoints wristband and produced by TouchPoints Inc. [32]. This solution provides not only emotional monitoring but also claims to relieve stress using stimulating electrical pulses [44]. Other devices that can be worn include: BioHarness, Equivital Sensor Belt, Zepher belt and Hexoskin which is clinically validated to provide reliable ECG data. The last product listed is called AIO Sleeve, developed by Komodo Technologies but it is only a consumer device which does not provide clinical grade data.

Recently, smart clothing is becoming the new trend for wearable devices especially for physiological monitoring and emotional assessment as it provides a seamless experience for the users compared to wristbands which can be obtrusive to some users. An example of such solutions is Hexoskin Smart Shirt, developed by Hexoskin Inc. [41], which incorporates fabric sensors that collect: ECG, heart rate, heart rate variability, respiration rate, and body movement data.

The need to collect multiple data (e.g., physiological and positioning), based on the listed devices, may require the use of multiple devices which can cause inconvenience to the user. Thus, it is evident that having one device that can collect all relevant data (i.e., physiological, movement, and positioning) is more practical solution. EQ02 LifeMonitor, from Equivital Inc., offers this capability where it can also collect the previous parameters and has additional features including body movement and GPS location tracking system.

VI. DISCUSSION

The previous section has reviewed some existing or forthcoming products which are either designed for individuals with autism/intellectual disabilities or can be adopted for this population.

It can be seen that most solutions provide either tracking or emotional monitoring which can be a drawback if they lack the other capability.

As it was seen earlier, individuals with autism spectrum disorder /intellectual disabilities can exhibit different kinds of challenging behaviours such as wandering and anxiety at the same time. From the reviewed products, it can be noticed that most commercial products can only offer one type of tracking. However, it would be more useful to inform the caregivers of the internal emotional state of the individual which may precede wandering so that they can take preventative measures to avoid harm for the individual or being exposed to unsafe environment. One listed device called, EQ02 LifeMonitor, is equipped with sensors that can provide the two functionalities. Using such a solution, clinicians and caregivers can objectively identify what the individuals with ASD/ID are experiencing physiologically, which could help in understanding the internal emotional state and the contexts and locations in which such behaviour is exhibited or escalated levels of anxiety are developed. From technical perspective, the target solution can use the unlicensed Bluetooth Low-Energy Protocol to transmit the physiological and positioning data to a remote recipient (e.g., smart phone) when the data can be processed locally in the wearable device and the useful information is only sent intermittently to the recipient to reduce the communication overhead and minimise the power consumption. It should be noted that other sensing modalities can include sound sensor and light sensor which can be useful to detect verbal aggression which is another kind of challenging behaviour.

VII. CONCLUSION

In this work, we conducted a review on commercially off the-shelf wearable devices suitable for monitoring and tracking individuals with autism spectrum disorder and/or intellectual disability. Specifically, we briefly explained the unique issues that those individuals experience such as challenging behaviours. Then, we reviewed the related physiological, behavioural, and location related sensors that can be used to monitor the internal emotional state, their activities, and track their location. After that, we surveyed the existing and emerging products in the market with various form-factors, examined their usefulness in practice, and talked about lessons learnt and their shortcomings.

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