Interactive Multi-Sensory Tactile Mat for ASD Children With Tactile Defensiveness Issues: A Preliminary Study

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Abstract

Autism Spectrum Disorder (ASD) according to the official website of Malaysia's Ministry of Health is "a long-term growth disorder that affects a child's thinking and information processes". Some ASD children may face issues with sensory processing such as tactile defensiveness. It is a condition where the sensory processing of an individual is over responsive which can be emotionally and mentally painful to affected individuals. The effect of the symptom can be reduced through intervention programs. However, keeping track of ASD children's response/reactivity various surface and textures may be difficult for the child's therapist or parents. This paper presents the development of a device specifically designed to assist ASD children with tactile defensiveness issue. The device consists of three modes: Measurement mode, Game mode and Education mode. The system is still in preliminary study and were tested with 5 healthy adults for system validation.

Keywords

Autism Spectrum Disorder, ASD, Assistive Technologies, AT, Tactile Defensiveness, Sensory

1. Introduction

Autism Spectrum Disorder (ASD) as according to the official website of Malaysia Ministry of Health is "a long-term growth disorder that affects a child's thinking and information processes". In Malaysia, out of 1000 children, 1-2 of them are suffering from ASD and the probability for it to occur in male is 4.7 times higher than female [1]. Some ASD children may face challenges with sensory processing. ASD child with difficulties in sensory processing may experience extreme sensitivity to loud sounds, bright colors and other sensory input that may seem normal to us. The issue can be further categorized into two categories which are hyposensitivity and hypersensitivity [2]. If a child is hypersensitive, they will often feel anxious and refuse participating in a task that is too intense. They may demonstrate emotional response/meltdown which can lead them to avoid sensory input as it is overwhelming for them. A hyposensitive child may not respond to sensory stimuli that others typically respond to.

Current research focuses on adapting evidence-based therapies into robotic platform. The robot used various traditional methods for intervention of ASD children such as Applied Behavioral Analysis (ABA) therapy. In previous literatures, robot is used as supporting tools for the therapist to stimulate and encourage the social skill of the children [3], [4]. The robot collects data from the ASD children to enhance effect of therapy. Various sensors were embedded with the robot to capture and collect information which can be further used to assess ASD children's behavior. The captured information can be analyzed by therapist for future improvement on the therapy session.

The activity of the intervention needs to be helpful in improving ASD children's social development, skills, or knowledge. To ensure the success of the therapy, cooperation from ASD children is important. It is essential to keep ASD children from losing interest during intervention. ASD children tend to be more comfortable interacting with a robot compared to human [5]. Next, the activity should be simple in nature to encourage ASD children to perform it independently with minimal guidance from the

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therapist or parents [6]. So, the activity for the intervention needs to be meaningful, interesting, and simple to understand for the ASD children.

[20] focuses on sensory processing issue for ASD children. This study designed a portable visual plus tactile game system. The main function of the device is to teach the child to read, spell and count using interesting game system and flexible mat as game controller input. The mat consists of both letter and number indicia which covers the electric circuit below the surface to send electrical signal to the processing unit. While this may be useful for some ASD children, we propose for a system that can help ASD children be exposed to various types of surfaces.

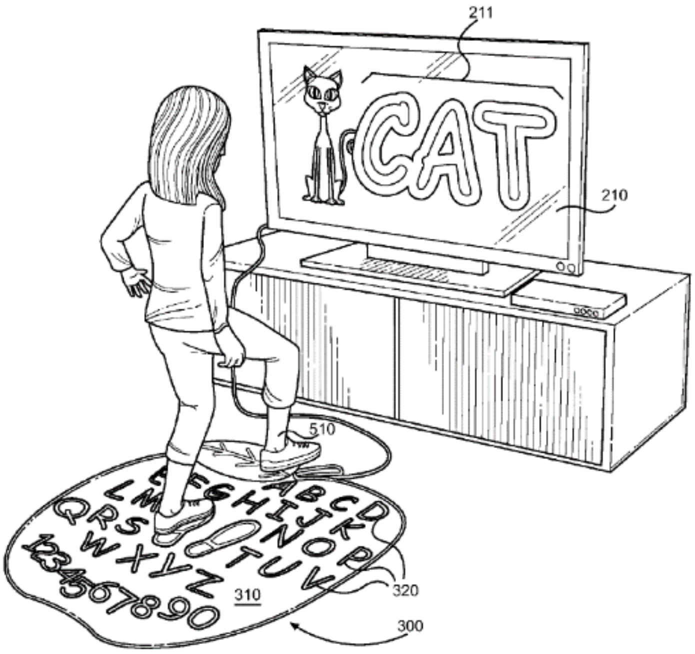


Figure 1. Perspective view of the system [20].

1.1. Contribution

To assist developmental growth of ASD children, they need assistance from adults or assistive tools to improve their skills. Various methods of intervention are currently being studied to facilitate development of skills for ASD children. Therapy for ASD children is usually comprehensive in nature, where they target different set of skills such as cognitive, social, fine motor and gross motor's development, the scope of this project focuses only on helping to reduce the tactile defensiveness issue in ASD children. Existing studies include using robot [7]–[10] to assist therapies/parents.

This device was designed to encourage ASD children with tactile defensiveness issues to overcome the fear of touching certain types of surfaces by distracting them with games/activities. Tactile sensor will be used to allow the ASD children to give input to the system. The system allows for therapist/parents to monitor meaningful data such as duration of touch on specific tactile mat. Simple and interesting intervention activities such as games and learning programs were developed. The activities may facilitate skill development of ASD children such as memory and cognitive skills. Additionally, the game mode may also stimulate the reaction speed and inhibitory control processes of ASD children. This project also investigates the different types of tactile surface and devices for ASD children and contributes to the development of an assistive tool specifically for ASD children with tactile defensiveness issue. The system is tested with several adults.

2. Methodology

In this section, we will discuss about the method in developing activities of intervention to achieve the objectives of the project. The discussion will be focusing on the hardware design and software utilized for this project. At the end of this section, the flowchart of the system was presented and discussed.

2.1. Sensory Integration Therapy

This system has been designed, to follow as closely as possible the sensory integration (SI) method. Sensory integration is a play-based therapy used to change how the brain reacts to touch, sound, sight, and movement. SI therapy helps the brain's nervous system better process sensory information through play activities. SI theory was originally developed to focus on the neurological processing of sensory information [11]–[13]. Purposeful behaviors can be disrupted by interferences in neurological processing and sensory information integration [13]. Planned and controlled sensory input, suitable with needs of the child were used during SI. In each session, a trained therapist artfully engineers the characteristics of the environment to create the “just-right challenge” [12], [14]–[16]. The activities are designed to help modulation of the nervous system, organization and integration of information from the environment which can result in future adaptive responses [12].

2.1.1. Role of play in sensory integration therapy

During SI therapy, ASD children will be exposed with sensory stimuli repetitively in a structured way and structured environment. This is to help the child’s brain adapt over time, allowing them to process and react to different stimuli and sensations more efficiently. Play is a significant factor in SI therapy. The use of play not only introduces your child to a range of stimuli, but it also helps to increase your child’s ability to tune out distractions and sensations that may cause them to experience an adverse reaction.

In a conventional occupational therapy, the OT will select an activity that is uniquely suited for the child. The child may play in a ball pit, play with sensory stimuli or play with toys of various sizes and textures. The OT will provide verbal cues to ensure play is done in a meaningful way (functional play). For our system, the child will engage with different tactile surfaces that has different uses for each mode. When done consistently, such sensory processing work may help improve ASD child’s spatial awareness and normalize their experience with different sensory inputs.

2.2. Hardware Details

During the development phase, the structure and materials of the device were thoroughly discussed and analyzed so that it is suitable and safe for ASD children. Arduino UNO were utilized as the microcontroller as it is widely available and cost-effective. As for the sensor of the system, some sensors were proposed for this project. The selection process of the sensor was based on the properties/features of the sensors and will be elaborated further in the next sub-section. To design the device, we considered the safety of the user. The mechanical part of the device must not contain any sharp edges that may hurt the ASD children. The material of the device must be hard and flexible to withstand the force exerted by the user.

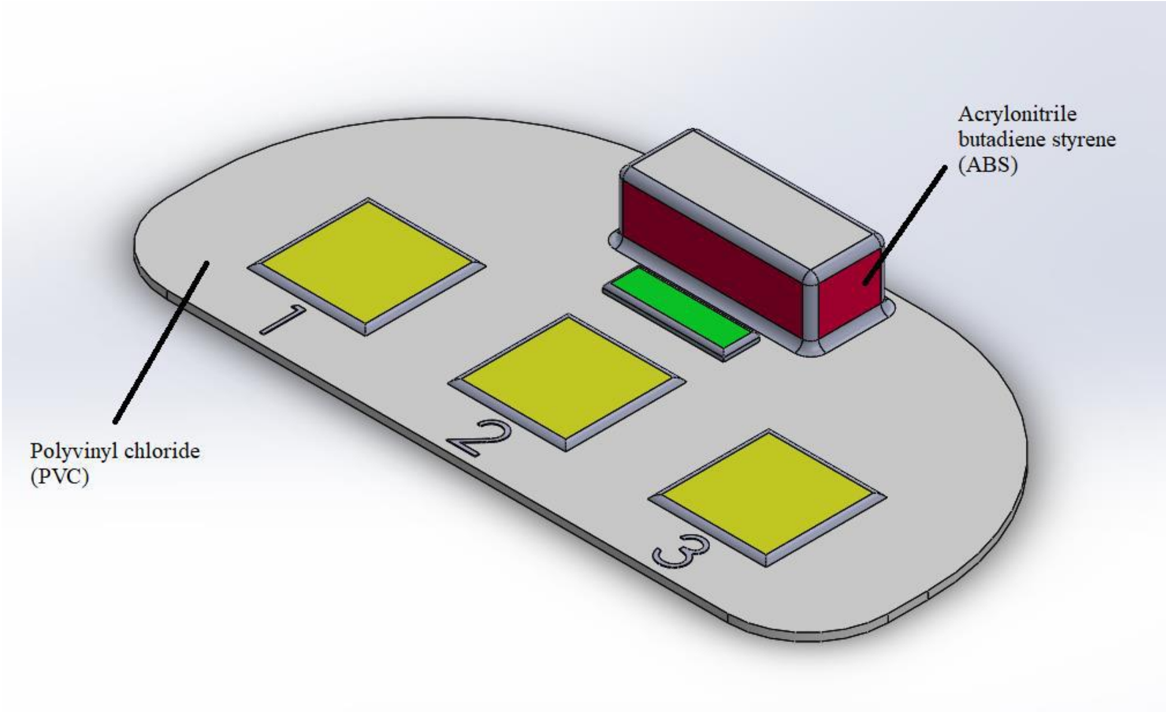


Figure 2. Design of the tactile mat.

2.2.1. Polyvinyl Chloride (PVC)

Polyvinyl chloride (PVC) is one of the most versatile plastic which compose of chlorine and ethylene. PVC can be divided into two forms which are rigid PVC and flexible PVC. For this device, flexible PVC will be used for the platform of the tactile mat. It is because PVC is a strong, durable, and lightweight material that is suitable for this application. PVC also has electrical insulation properties that will not disturb the flow of electrical current in the device.

2.2.2. Acrylonitrile butadiene styrene

For the housing of the electrical component, we will use Acrylonitrile butadiene styrene (ABS) as the material of the cover. ABS is suitable to use for indoor application and not in harsh environment. The desired properties of ABS for this device are the resistance toward impact and good structural strength and stiffness. It also has great electrical insulation properties.

2.2.3. Tactile Surface

For this project, three tactile mats with different surface properties such as roughness, compliance, coldness, and friction were used. The type of the surface are fabric surface, plastic surface, and rough surface.

2.2.4. Microcontroller

The microcontroller that will be used in this project is Arduino Uno. This microcontroller is suitable for developing interactive devices. It can take inputs from analog sensors. Arduino can be operated in standalone device by simply connect it to power supply. There are many other advantages of using Arduino Uno as it is an open-source electronics platform, has simple programming environment and is inexpensive.

2.2.5. Bluetooth Module

The Bluetooth module of the device is Bluetooth Serial Transceiver HC-05. It is an easy-to-use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. Its communication is via serial communication which makes an easy way to interface with another device. HC-05 Bluetooth module provides switching mode between master and slave mode which means it able to use neither receiving nor transmitting data.

2.2.6. Force sensing resistor

Force sensing resistor (FSR) is a sensor to measure the applied force. It is a resistive type of sensor where the resistance of FSR is inversely proportional to the applied force. When, a force is exerted onto the FSR, it will reduce the resistance of the FSR. At the same time, it will cause the output voltage to flow and send an analog signal to the Arduino pin. FSR is suitable for human-machine interface application with a sensing range around 20g to 5Kg. It is relatively thin and flexible to be placed under the tactile mat.

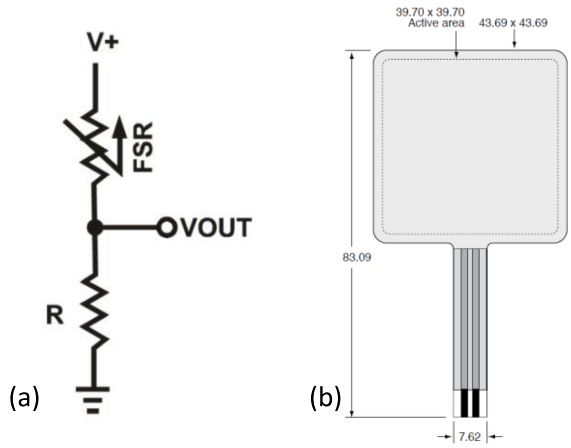


Figure 3. (a) Voltage divider with FSR sensor, (b) FSR01.

The applied force can be measured using the voltage divider circuit with the FSR and a reference resistor. The circuit creates a variable voltage output that connect to the analogue input pin of the Arduino Uno. The output voltage, Vout of the voltage divider is the voltage drop across the resistor which can be express by the following equation:

$$V_{out} = V_{in} \frac{R}{R + R_{FSR}}, \tag{1}$$

From the equation, the output voltage is inversely proportional to the resistance of FSR. The range of the measured force is depending on the value of the resistor.

2.2.7. Velostat

This conductive material also known as "Velostat" or "Linqstat" is a pressure-sensitive materials that suitable for making flexible sensors. When squeezing it will reduce the resistance of the materials. To create a pressure sensor using Velostat, additional materials are needed such as conductive materials such as aluminium foils, duct tape and flexible cable. The Velostat is placed between two layer of conductive materials which provide analog value in the form of resistance.

To obtain the data of the resistivity of the sensor, we can also implement a voltage divider circuit consist of the sensor and reference resistor [17].

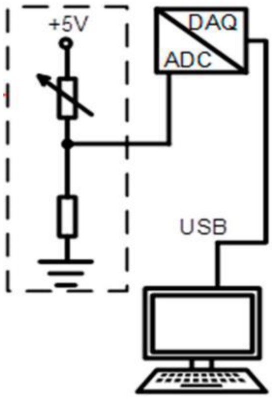


Figure 4. Voltage divider circuit [9]

The resistance of the sensor is calculated using the following equation:

$$R_V = \frac{V_{out} R_{ref}}{V_{in} - V_{out}}, \tag{2}$$

Where, R_{ref} is the resistance of the reference resistor, V_{out} is the output voltage from the measuring circuit, R_V is the resistance of the velostat at the measurement point, and V_{in} is the measurement input voltage applied to the circuit.

2.2.8. Capacitive Sensor

Capacitive sensor is a sensor electrode that measures the capacitance change when conductive object is placed near the sensor [18]. The capacitive sensor measure capacitance distributed from the electrical properties of human body [19]. When the two conductors, sensor electrode and human body are placed close to each other, a capacitance known as the parasitic capacitance, C_P is made.

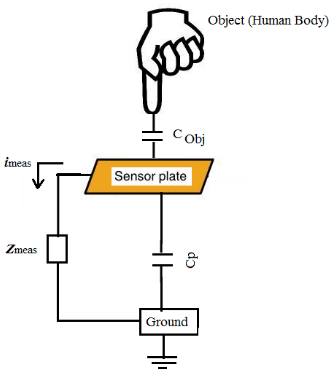


Figure 5. The circuit of capacitive sensor [11].

The change in the capacitive coupling can be measured at the electrode as a change in the electrode voltage relative to the ground reference. The voltage of the electrode can be calculated from the capacitive voltage divider of C_{obj} and C_P which is the product of current, i_{mean} and the impedance, Z_{mean}.

$$V = i_{mean} * Z_{mean}, \tag{3}$$

The 'capacitiveSensor' library turns the Arduino pins into a capacitive sensor. It toggles the send pin to a new state and then waits for the receive pin to change to the same state as the send pin. A variable is incremented inside a while loop to time the receive pin's state change. The method then reports the variable's value, which is in arbitrary units. Each sensor requires a medium to high value resistor and a piece of wire and a conductor such as aluminium foil.

2.2.9. Power Supply

4 AA battery holder with 4 rechargeable AA batteries, at 1.5V each with. It is because they are efficient and give the Arduino Uno the necessary amount of voltage at 6V. The battery holder not only has an internal switch for turning on the Arduino, but it also has the DC jack for easy wiring to the Arduino Uno.

2.3. Software Details

To develop this system, the software used is Arduino IDE and MIT App Inventor. The Arduino IDE will be used to control the microcontroller, receive input from the sensors, and send data. For this project, a smartphone application was developed by using MIT App Inventor. The application is used as graphical interrace for the intervention activities of ASD children.

2.3.1. Arduino IDE

Arduino IDE is a cross-platform application that is written in functions from C and C++. The open-source Arduino Software (IDE) makes it easy to write code and upload it to the Arduino board. It can run on Windows, Mac OS X, and Linux. The environment is written in Java and based on processing and other open-source software. In this project, Arduino IDE is used to write the code for receiving ac input from the sensors and sending data to the smartphone application through the Bluetooth module.

2.3.2. MIT App Inventor

MIT App Inventor is an intuitive, visual programming environment that allows to build fully functional apps for Android and iOS smartphones and tablets. It uses a graphical user interface (GUI) and blocks-based coding program that allows users to drag and drop visual objects to create an application. This project used MIT App Inventor to develop a graphical application for the intervention of ASD children and store the data and result into the smartphone memory storage.

2.4. System Design (Hardware and Software)

Figure 6 (a) and (b) shows the overall workflow for hardware and software of the system. If the Arduino is connected with the smartphone application, it will send the data of the sensor to the application. Then, Figure 6(b) shows the flowchart of smartphone application. When the application runs, the application will display the modes available. The user can choose the mode, then, the application will receive data from the Arduino via Bluetooth module. After receiving data, the application will give feedback to the user for their input. At the end of the intervention, the application will record the data and save it in the device storage.

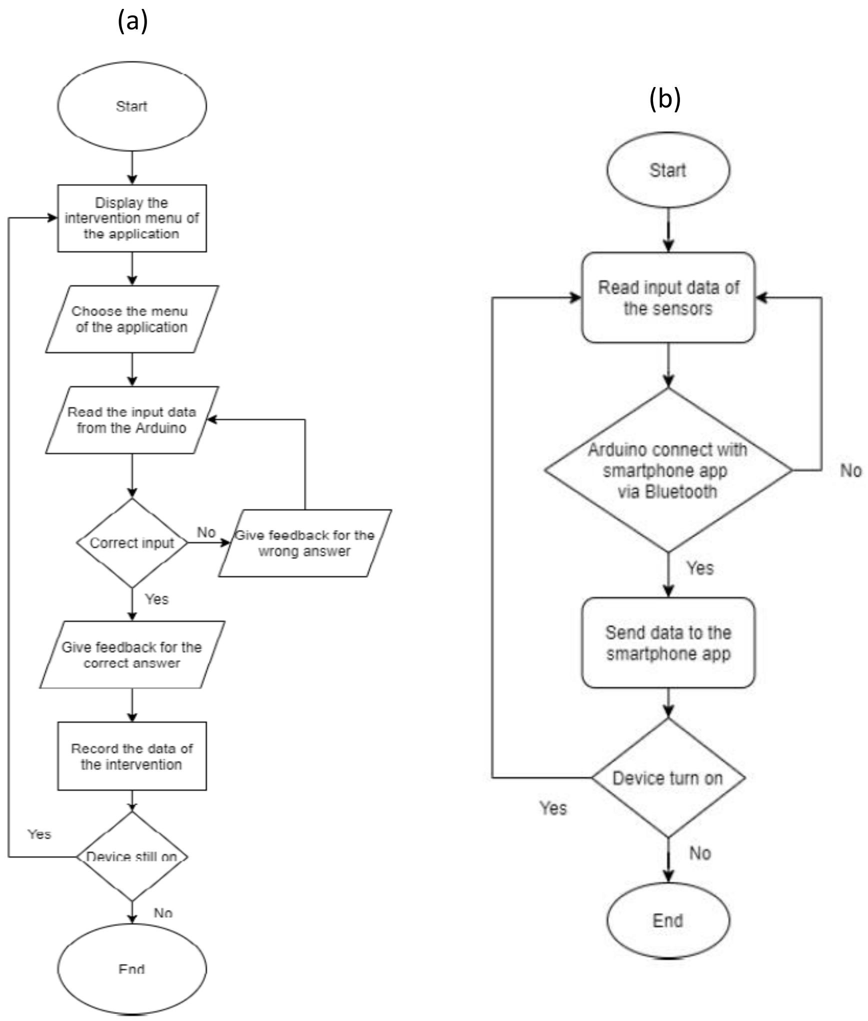


Figure 3. (a) Flowchart of the hardware, (b) Flowchart of the mobile application.

3. Results and Discussion

In this section, we will discuss the sensor selection process and the development of the smartphone application for the system. For the sensor selection process, three sensors (FSR, Velostat, and Capacitive Sensor) were tested and evaluated. Next for the application development, we will introduce the modes available for the smartphone application for the system. The flow of the program and the simulation of the modes will be discussed.

3.1. Selection of sensor and development of Android application

3.1.1. Sensor selection

In this project, three sensors were proposed for detecting and measuring the force exerted on the tactile mat which are FSR, Velostat, and capacitive sensor. Capacitive sensor is relatively cheap, flexible, and customizable, but the conditioning circuit and computation of the sensor is complex. The delay between the send pin changing and the receive pin changing is determined by product of resistor and the capacitance at the receive pin and sensor pin. The sensor pin measures the capacitance value of human body which is difficult to estimate it. Then, other source of conductor may interrupt the measurement of the capacitance.

On the other hand, FSR and Velostat have similar properties. Based on the datasheet of FSR, the range of the force that it can measure is up to 5Kg. Next, based on Figure 4, Velostat have less force range which is up 350g. The graph in Figure 4 is developed by measuring the resistance of the Velostat by using multimeter and weight. The downside of FSR is its limited active area and is less flexible than Velostat. The tail of FSR cannot be kink or crease because it will break the printed conductor of FSR and damage the reading. Thus, in this project Velostat is chosen as the sensor to measure the force exerted on the tactile mat due to its' reliability,.

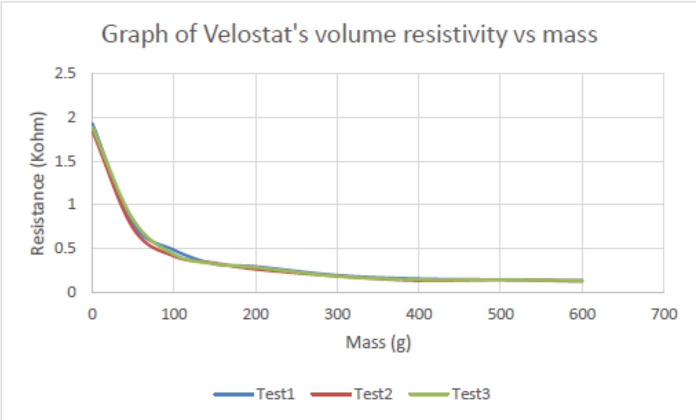


Figure 4. Graph of Velostat's volume resistivity vs mass.

3.1.2. Circuit configuration

The sensors were connected to Arduino analog pin. The analog pin can read the voltage value as 0 to 1023. The following equation is used to calculate the actual value of the output voltage of the sensors.

$$V_{out} = (\frac{V_{in}}{1023})V_{read}, \tag{3}$$

Where, V_{read} is the reading of analog pin. Then, the resistance of the sensor can be calculated using voltage divider formula and the force exerted on the sensor can be measured from the graph of Figure 21. The reference resistor used in this project is 2.2 MOhm.

$$R_V = \frac{V_{out} * 2.2 * 10^6}{V_{in} - V_{out}}, \tag{4}$$

3.1.3. Prototype of the system

The Velostats were placed and sew under the tactile mats. It was connected with the Arduino using alligator clip under the mat. All the electrical component except for the battery holder were located inside the device housing. The device can be turned on using the switch of the battery holder. Prototype of the system and the circuit configuration can be referred to in Figure 6.

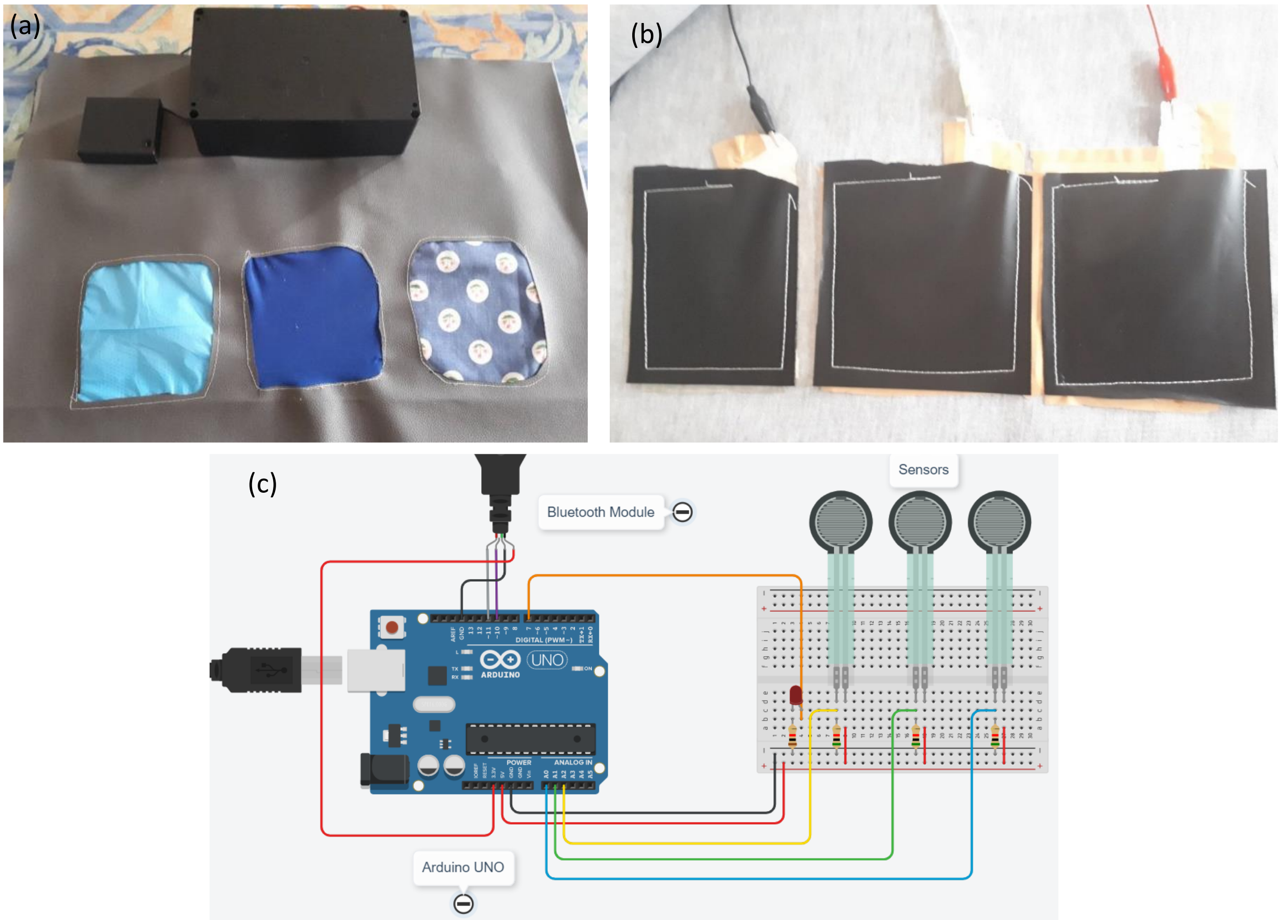


Figure 5. (a) Prototype of the device, (b) The Velostat of the tactile mat, (c) Circuit configuration

3.1.4. Android application

The Bluetooth module embedded with the device needs to be paired to the phone before starting the application. It is important to set the Clock interval for the Bluetooth client in MIT App Inventor to 100 or 0.1 second. The Clock interval needs to be lower than Arduino delay. When the Clock interval is slower than Arduino delay, the application cannot process the information when the buffer is being filled.

When the application is started running, it will display the mode of the application. The application consists of 3 modes which are measurement mode, game mode and education mode. The user can choose the modes by touching the respective image of the mode in the application.

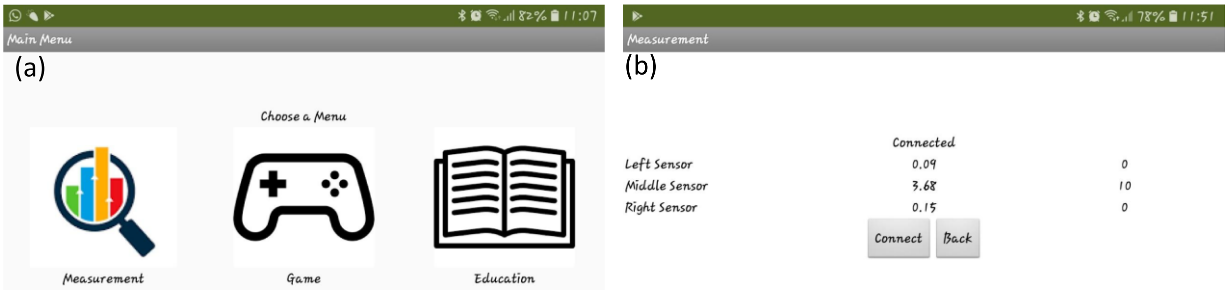


Figure 6. (a) Main menu of the application, (b) Measurement mode of the application

For the measurement mode, the application displays the amount of force the user exerted on the tactile mat. The Arduino will measure and calculate the output voltage of the sensors by using voltage divider before sending it to the application. There are two types of data that will be display on this mode: (a) the output voltage of the sensor, (b) the duration of time the force is exerted on the sensors. The highest reading of the output voltage and the time duration of the force is exerted will be recoded into the smartphone memory.

In game mode, there are 2 types of games that can be played by the user which are “Whack a mole” and “Simon said”. The rule of the first game is to touch the tactile mat when the “mole” pops up on the screen respective to it position. For the second game, the user needs to choose the set of sequence of “Light” shine on and memorize it. Then, the user must insert the input by touching the tactile mat according to the sequence shown earlier. After the user input the answer, the application will give feedback whether the answer is right or wrong. In this mode, the application will record the number of correct answer and the time for the user to complete the game.

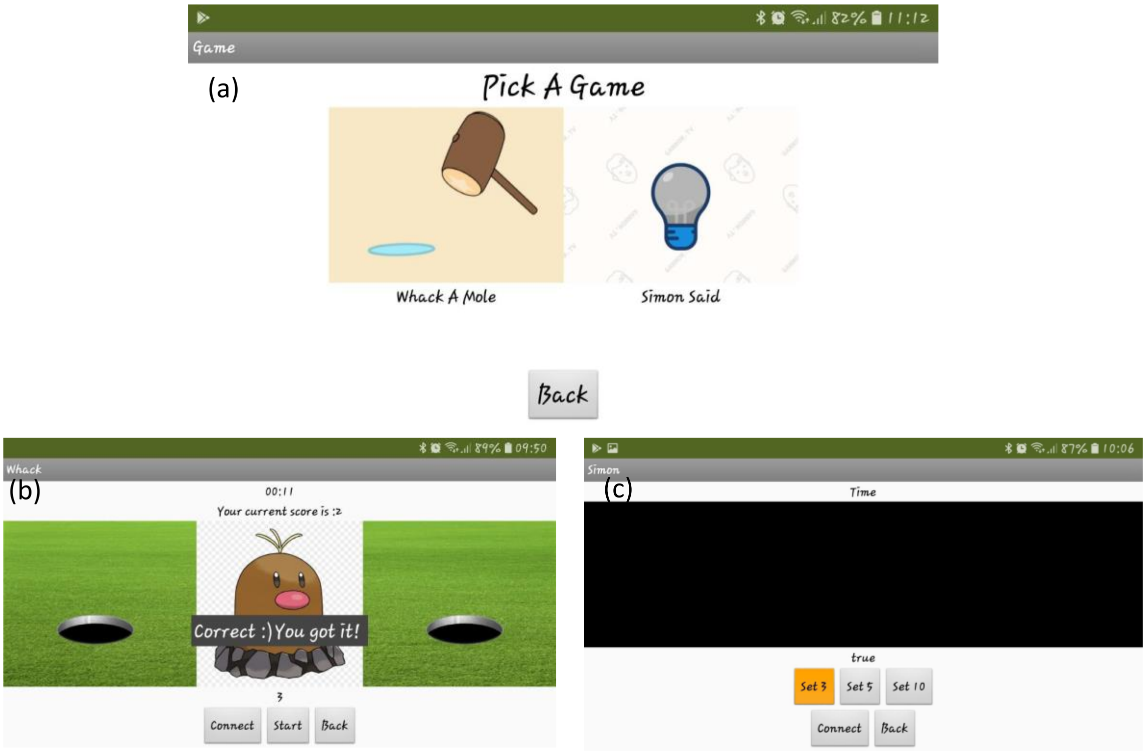


Figure 7. (a) Game mode of the application (b)Whack A Mole game, (c) Simon Said game.

Lastly, for education mode, the application will give a mathematical quiz for the user to answer it. The quiz can be addition or subtraction problem with multiple choice answer. The user needs to choose and touch the right tactile mat to answer the question. The result of the quiz will be recorded into the smartphone storage. The application will give feedback and display the right answer to the user.

3.2. Rationale of each mode

Each of the mode has its own function. By letting the ASD children interact with the device, it allows them to get used to the surface of the tactile mat. The measuring mode is used to identify the comfortableness of the ASD children toward a particular surface. If the ASD children feel safe to touch the tactile surface with a certain amount of force, the device will record the data and the therapist will understand the condition of the ASD children when he/she inspects the recorded data. Thus, the therapist can decide the next step of the intervention for the ASD children with tactile defensiveness issue.

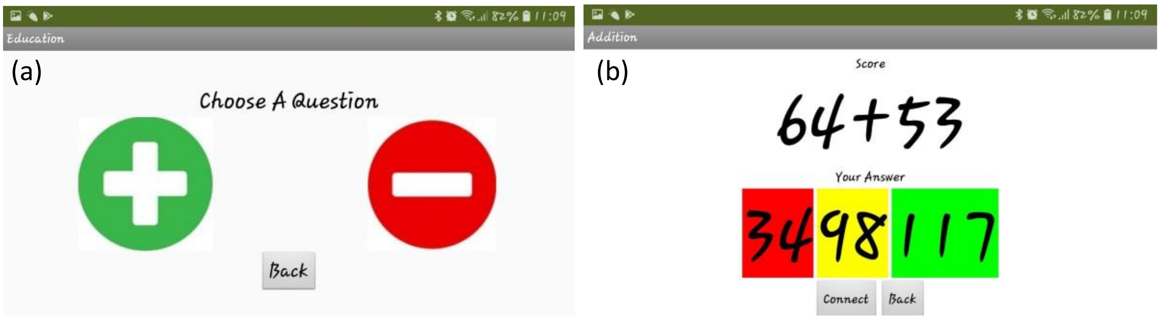


Figure 8. (a) Education mode of the application, (b) Addition question of education mode.

The game mode tests the memory of the ASD children. During the activity of "Whack a mole" game, it tests the reaction of the ASD children to touch the tactile mat when the "mole" pops up. The faster the ASD children touch the tactile mat, the better the result of the game. Then, for "Simon said" game, the ASD children require to memorize the sequence of the "lights" shine on. Thus, it stimulates the memory of the children to remember the sequence and give a correct answer. For the sense of accomplishment of the ASD children, the device will display the recorded time for the ASD children to complete the game. While playing the game, it can also help the child with tactile defensiveness issues (if present), being distracted with the game may help ASD children to touch the surfaces without being repulsed by the texture of surface.

Then, the education mode enhances the ASD children's knowledge and cognitive abilities. The mathematical knowledge that the ASD children learn in school can be strengthened with a simple quiz. When the ASD children gives input (the answer), the device will give a feedback for the ASD children to confirm whether their answer is correct or not.

3.3. Reliability of the system

Due to limitations we faced during the Movement Controlled Order (MCO) imposed by the Malaysian government during COVID-19, which has caused for all center for ASD children to close, this project focuses more on the reliability of the system instead of the efficacy. This will allow for future researchers to test on the efficacy of the system once operation of centers for ASD child resume. In this project, 5 adult participants were selected to evaluate the reliability of the developed system. The participants tested each mode in the application to check whether the system work as intended. The system is evaluated based on the response of the sensor, the flow of the application and the recorded data of the application. The feedback and recommendation from the participants were received for future improvements.

Figure 10 shows the reading of output voltage of the sensor. The participants will place their fingers with same force onto the sensor. The test checks the repeatability of the sensor to detect the exerted force of the fingers. The figure shows that the reading of output voltage of the participants in each test have a close range of reading. Thus, the repeatability of the sensors is proven.

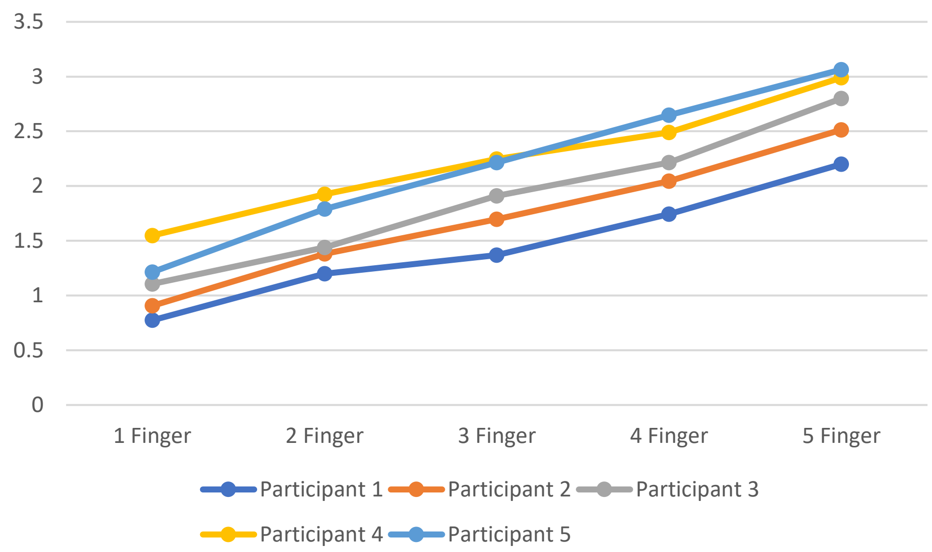
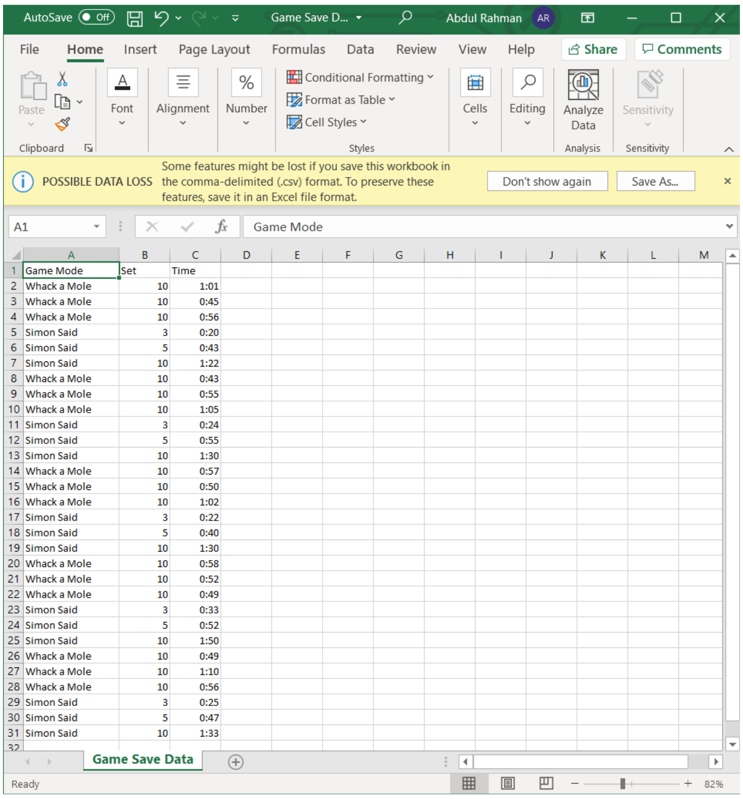


Figure 9. Graph of Average voltage reading (V) vs. Number of Fingers.

For the last test, the participants were asked to freely play with the application. Aim of this test is to check whether there was any error while running the application. Some run time errors were found during the test. Adjustment of coding were done to resolve the errors.



Game Mode	Set	Time
Whack a Mole	10	1:01
Whack a Mole	10	0:45
Whack a Mole	10	0:56
Simon Said	3	0:20
Simon Said	5	0:43
Simon Said	10	1:22
Whack a Mole	10	0:43
Whack a Mole	10	0:55
Whack a Mole	10	1:05
Simon Said	3	0:24
Simon Said	5	0:55
Simon Said	10	1:30
Whack a Mole	10	0:57
Whack a Mole	10	0:50
Whack a Mole	10	1:02
Simon Said	3	0:22
Simon Said	5	0:40
Simon Said	10	1:30
Whack a Mole	10	0:58
Whack a Mole	10	0:52
Whack a Mole	10	0:49
Simon Said	3	0:33
Simon Said	5	0:52
Simon Said	10	1:50
Whack a Mole	10	0:49
Whack a Mole	10	1:10
Whack a Mole	10	0:56
Simon Said	3	0:25
Simon Said	5	0:47
Simon Said	10	1:33

Figure 10. The file of recorded data of game mode.

4. Conclusion and Future Directions

4.1. Conclusion

In this report, the study has discussed about the development of supporting tool for the ASD children with tactile defensiveness issue. The device is focused on the intervention activity that can develop skills of ASD children and help them overcome tactile issues. However, due to MCO, the project was not possible to be tested on the ASD children. Thus, the project was tested with adults to measure its' reliability. The use of interactive tactile surfaces encourages the ASD children with tactile defensiveness issue to touch different surfaces. The device stimulates three different senses in the child's sensory system, which are visual, auditory, and tactile senses. Other than that, the data storage system informs the therapist and parents on the progress of the intervention of the ASD children.

In conclusion, an assistive tool for ASD children with tactile defensiveness have been developed. The reliability of the developed system was evaluated by 5 participants.

4.2. Future works

For future works, the device can be improvised by developing more intervention activities. By doing so, the device can engage with ASD children and encourage them to explore the device. Furthermore, the number of tactile mats can be increased to expose the ASD children to different types of surfaces. Lastly, the system must be tested to ASD children with tactile defensiveness issue to evaluate the efficiency of the system.

5. Acknowledgement

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