Oral Therapeutic Tool for Speech and Feeding Therapies

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***Abstract*—The ability to move the tongue from side to side inside the mouth and chew or apply pressure on food is an essential skill for feeding therapy and development. Those abilities are usually called *Tongue Lateralization*. To put it simply, it is how we "scavenge" those left-over food particles inside our teeth, cheeks, the gums, and lips. It is also essential for toddlers to develop speech skills as well as eating and chewing skills. These skills include awareness, strength, coordination, movement, and endurance of the lips, cheeks, tongue, and jaw. However, many children find difficulty in performing these tasks, which often prevent their growth and skills development. Currently, many exercises and tools can help children with these problems. However, most of them have low quality, easy to break, and not user-friendly. For example, parents may give the tools to their child to practice, but they would not know if their children are making progress. Not only that, in some cases, it is difficult for a therapist to keep track whether the patients are actually exercising or doing it properly since they cannot be with them 24/7. Therefore, we develop a tool by integrating sensors and Wi-Fi-enabled microcontroller into a therapeutic tool and develop an algorithm to overcome the sensory issues which are related to the practice times so that it can give better feedback on the patients' progress. By the help of this tool, parents and therapists can monitor the patients' progress in real time and assess whether these exercises are effective.**

***Index Terms*—Speech Therapy, Feeding Therapy, Internet of Things, Therapeutic Tools.**

I. Introduction

According to research from Center for Disease Control and Prevention, one in twelve children ages 3–17 has had a disorder related to voice, speech, language or swallow in the past 12 months, and only half of them receive proper intervention [1]. Among children who have a voice, speech, language, or swallowing disorder, 34 percent of those ages 3-10 have multiple communication or swallowing disorders, while 25.4 percent of those ages $11-17$ have multiple disorders [1]. Also, the data indicate that of the 7.7 percent of children with a communication or swallowing disorder, 5 percent have speech problems; 3.3 percent have language problems; 1.4 percent have voice difficulties, and 0.9 percent have swallowing difficulties [1].

In many cases, speech and feeding disorders can co-occur in children, and it can get quite complicated to treat these disorders at the same time. The first important aspect of oral therapy is feeding therapy. It is used to help infants and children who have difficulties in sucking, chewing, feeding or swallowing. The sooner these problems are addressed for children, and they are treated, the better they grow and have better outcomes. The second aspect is speech therapy which is a treatment to problems with the actual production of sounds or problem understanding or putting words together to communicate ideas. Since speech is the most vital skill of human, the therapy should begin as soon as possible. However, speech and feeding disorders can only be identified until children have reached the ages at which various speech and feeding abilities are expected. However, children under the age of approximately 30 months to 36 months are often difficult to evaluate because they may be reluctant or unable to engage in formal standardized tests of their speech and feeding skills [2]. Therefore, we need a device that is not only a toy for children but also can help them exercise their oral functions and monitor the progress of them by using the Wi-Fi enabled microcontroller and sensors. Therefore, our *objective* in this paper is to develop a tool by integrating sensors and Wi-Fi-enabled microcontroller with into therapeutic tools and develop an algorithm to overcome the sensory issues which are related to the practice times so that it can give better feedback on the patients' progress. Our key *contributions* can be summarized as follows:

- To follow the patients' progress, a therapy tool is developed. The device includes pressure and heat sensors. The data which is collected by the device is sent to Cloud over Wi-Fi.
- To display the progress reports correctly, an algorithm is proposed. In this algorithm, we consider the collected data with practice time and speed.
- To make the data more accessible and beneficial, a user-friendly, smart-phone application is created. With the application and user-friendly interface, doctors and parents can sort, calculate, filter the data or compare it with other patients' data to come up with their assessments.
- To test the efficiency of the device and the created application with the algorithm, the data collection from sensors and the time to transfer the collected data from the device to cloud platform have been analyzed.

By the help of this tool, parents and therapists can monitor the patients' progress in real time and assess whether these exercises are effective.

The rest of the paper is organized as follows: In Section II, the related works are summarized. Section III explains the system model. The created tool and application are explained in Section IV. Section V discusses the analysis part and, finally, Section VI has the concluding remarks and plan for future works.

II. Related Works

The Internet of Things is a relatively new field of research. Thus its potential use for healthcare, especially in the therapy area, is still in developing. In this section, the Internet of Things will be explored, and its suitability for healthcare will be highlighted. Also, several pioneering works toward developing healthcare IoT systems will also be discussed.

A. The Internet of Things

There are many definitions of the Internet of Things (IoT), however, basically, it can be described as a network of devices interacting with each other via machine to machine (M2M) communications through the Internet, which allows the collection and exchange of data [3]–[5]. This technology enables automation within a broad range of industries, as well as allowing for the collection of big data. Referred as the driver of the Fourth Industrial Revolution [6], Internet of Things technology has found commercial use in many areas such as air quality monitoring [7], smart parking solution [8], precision agriculture [9], and forest fire detection [10]. Extensive research has also been conducted into the use of IoT for developing intelligent systems in areas including traffic congestion minimization [11], structural health monitoring [12], crash-avoiding cars [13], and smart grids [14]. Not only that, IoT-based technology is also used in many aspects of healthcare such as remote prescription [15], smart continuous Glucose monitoring for diabetes patients [16], inhaler monitor for asthma patients [17], ingestible sensors [18], or Parkinson patients monitor [19] just to name a few. While some of the fields that were mentioned above appear somewhat different from therapy, the research conducted within them verifies the plausibility of an IoT-based healthcare system. Existing systems in other areas have proven that remote monitoring of objects, with data collection and reporting, are achievable. This can, therefore, be expanded and adapted for monitoring the health or healing progress of people and reporting it to relevant parties such as nurses, doctors, emergency services, parents, and healthcare centers.

B. Internet of Things in Oral Therapy

Specifically, in the field of oral therapy, according to the statistic of National Institute of Deafness and Other Communication Disorders (NIDCD), only 50 percent of children with some form of oral disorders such as voice, speech, language, and swallowing receive proper treatment [20]. Currently, in the market, there several companies [21]–[26] that produce oral therapy tools. Many current tools are not smart or connected. However, some of the tools [24]–[26] are capable for data collections, but limited in terms of auto evaluations and detect the feeding and speech interventions requirements. As a result, customers do not have many choices in the market. On the other hand, the available tools for treatment on the market right now are quite expensive, which ranges from $30 [27] - $2000 [24] and are somewhat fragile [27]. Not only that, the cost of going to a therapist and booking therapy sessions are also quite high. Usually, a patient would need several sessions since that is the only way for the therapists to tell if the patients are making progress [28].

On the other hand, in the Age of Technology, Internet of Things allows us to convert small old-school therapy tools such as the Ark's Z-Vibe [29] into a smart device with sensing, processing and communication capabilities, which enable the integration of sensors, embedded devices and other 'things' ready to understand the environment, collect data, and communicate with other devices. As we discussed above, the tools available for speech and feeding therapy are quite limited. Therefore, a smart therapy device based on the Internet of Things paradigm is proposed for not only helping children exercise oral functions but also monitoring the biomedical signals and assessing their progress over time. This proposed device can communicate with cloud services and other mobile environments with intensive data acquisition. The real-time data acquired by these devices presents a clear social objective of being able to assess whether the exercises are effective and identify if the patients need more attention.

III. System Model

Fig. 1 demonstrates a simple example of how this device captures the information and send it to the cloud. First of all, the therapeutic tool vibrates motors to help stimulate and exercise the patient's oral muscle more effectively. It has a rectangular tip that is bumpy on one side, striated on the other, and smooth along the edges. These textured surfaces provide tactile input, awareness, and sensation for patients. It can be used to stimulate the gums, palate, lips, cheek, and tongue by tapping, stroking, and applying gentle pressure. Secondly, the device also is integrated with low-power sensors and a microcontroller that can collect the pressure applied to the device, then send the data to the Cloud API through Wi-Fi.

Another important aspect of this tool is the Cloud API and online database. Collected data from the patients is sent to the cloud. In the cloud, the server analyzes the data and assess whether the patient is making progress, or the exercises are effective for them. Not only that, but we have also developed a mobile application that can help parents and doctors' access to their children or patients' data. With the algorithm and user-friendly interface, doctors and parents can sort, calculate, filter the data or compare it with other patients' data to come up with their assessments. Also, the device will be less than six inches in length, super lightweight, compact, portable, and suitable for patients of all ages. It also follows the USA medical grade and the Food and Drug Administration (FDA) compliant [30].

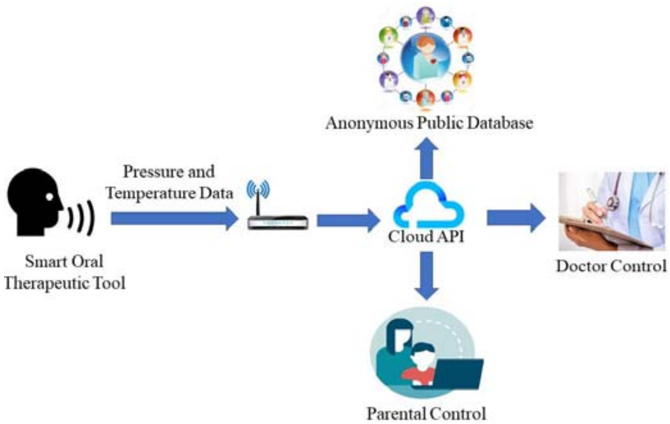

Fig. 1: The system model of the therapeutic tool.

A. Sensors

These tools endure much pressure. Therefore, we need a sensor that is affordable, small, replaceable, and stable. For these reasons, we decided to go with the Round Force-Sensitive Resistor (FSR) - Interlink 402 (Fig. 2) [31]. These sensors allow us to detect physical pressure at low cost. It has a resistor that changes its resistive value (in ohms Ω) depending on how much it is pressed. These sensors are relatively affordable, consume low power, and are easy to use.

Fig. 2: Round Force Sensitive Resistor [31].

B. Vibrate Motors

The devices are also be combined with medical vibrating oral motors that helps provide tactile oral cues, direct the articulators, stimulate the oral muscle, increase oral awareness and tone, decrease mouth stuffing, drooling, oral defensiveness, and texture aversions. Not only that, the gentle vibration from this motor provides a sensory stimulation which can increase oral focus and draw more attention from the patients to their lips, tongues, cheeks, and jaws. Moreover, the motor also aligns with FDA compliant [30] which means there will be no lead, phthalates, PVC, BPA, or latex (Fig. 3) [32].

C. Microcontroller

Another aspect of this product is IoT ability; for this reason, we need to use a WiFi-enabled microcontroller. Moreover, it needs to be small, compact, cost-effective for mass production, and configurable for future updates. After taking those mentioned factors into consideration, there is four hardware that meets the requirements: Spark Photon, NodeMCU, and Pro Micro ESP8266 [34]–[36]. All of them have computing ability, support full TCP/IP stack and partial Secure Sockets Layer (SSL), small size, and affordable price. However, the NodeMCU is the most viable choice for this project not only because it has the most robust CPU compared to the rest, but it is also the most affordable one (currently, $5.00) compared to those models that have the similar configuration. Moreover, with built-in Wi-Fi compatibility, it allows us to integrate IoT application into our tools without worrying about the hardware.

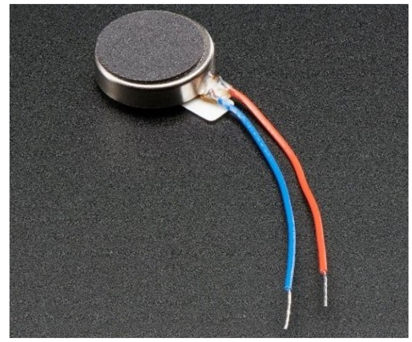

Fig. 3: Vibrating Mini Motor Disc [33].

Furthermore, the NodeMCU consumes just a minimal amount of power and can even run on 9 Volts battery which makes it versatile and flexible in many situations [37]. Despite the size of just a quarter, this microcontroller is powerful enough to control, modify, and gather data from many sensors at the same time. Additionally, there is a massive active community of developers and builders who contribute thousands of powerful modules for NodeMCU (Fig. 4) every day, and most of them are free which could significantly reduce the cost of this product.

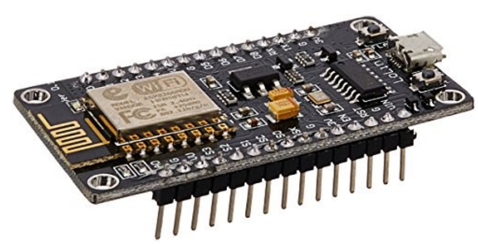

Fig. 4: NodeMCU ESP8266 Microcontroller [34].

IV. The Tool and Algorithm

In this section, we will explain the prototype and the algorithm to assess the personalized data with the benefits of the tool.

A. Tool

Research in related fields mentioned above has shown that remote health monitoring and analyzing is plausible. However, the most important factors here are the benefits it could provide to us in many aspects. With the Internet, the tools could be used to monitor the progress of patient anywhere, anytime as long as they have an Internet connection. That would save the time, money, and effort on booking appointments with therapists, driving there and having them to check every week to see if they are making progress. It might not seem like a big deal for those who live in an urban area, however, for those who live in rural area or not having transportation, this could be a huge change for them since they can get the result from a doctor without having to be there physically.

Furthermore, it also provides a much easier way for a doctor to access all patients' data, which would give a better picture of the patients' progress. Essentially, it can improve access to therapy resource while reducing strain on the physical healthcare system and can also give parents as well as doctors better control over their children's progress at all times.

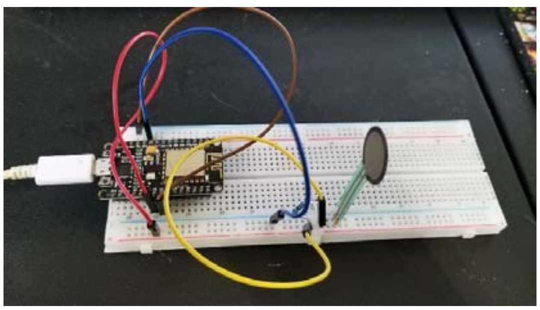

Fig. 5: IoT Therapeutic Tool Proof of Concept Model.

Fig. 5 shows the proof of concept of this device, with the force sensor and the NodeMCU microcontroller. Since the NodeMCU has the ability to connect to the WiFi, it can send the data directly into the cloud, and we can receive the real-time data sensor through the mobile application app like the demonstration in Fig. 6. From the mobile application as shown in Fig. 6, the pressure results can be shown in the graph format. As shown in the Fig. 6, live data can be observed with 1-2 second delays for pressure. Additionally, hourly, six hourly, daily, weekly, monthly, three monthly, yearly, and all pressure activities can be observed from the mobile application. Similarly, temperature and frequencies of the activities can be observed.

Fig. 6: Graphical User Interface of Pressure Sensor.

Algorithm 1 Algorithm for data analysis for personalization

Input: Collected data [] {For each minute}
Report: Reports for each minute [] {Report can be custom range}
Initialization :
x = calculateIndividualizedThresholdsforSenses() {From initial practice and average of the previous collected data}
y = findSlownessAndWeaknessTimeInMinute() {Speed decrement in every minute from the previous collected data}
LOOP Process
for $i = 0$ to $collectedDatalength$ **do**
  if $(|data[i] - y| \leq x)$ **then**
    Reports[i] = Need Improvement
  else if $(|data[i] - y| == x)$ **then**
    Reports[i] = No Changes
  else if $(|data[i] - y| >= 2 * x)$ **then**
    Reports[i] = High Sensitivity
  else
    Reports[i] = Regular Improvement
  end if
end for
return $Reports$

B. Algorithm

The data after being collected and processed in the client side will be sent to the Cloud API. As currently, we are using the free service of Swagger API [38] to host our database and service. The biggest advantage of using a third party Cloud API service is the scalability. As the number of users increases, the cloud service will scale accordingly without worrying about the hardware. In the cloud, Algorithm 1 will assess the performance and effectiveness of the therapy exercises based on the pressure, intensity, and temperature that collected through the device. Specifically, first time user will have an "entry practice session" to collect the base performance of the user. Over the next sessions, if the performance is not improved more than a certain percentage or even losing skills, the exercise will be identified as ineffective. It is also possible the activity can increase sensitivity more than the expected amount. Therefore, therapists can react accordingly to the result. Algorithm 1 uses two important parameters which are dynamic sensory thresholds and the average activity frequency per minute to track the progress. However, while measuring the progress, the speed decrement rate due to the

TABLE I: Average pressure, frequency, temperature in different time intervals

Time (Minute)	Average Pressure (kp) (The pressure was averaged in each minute)					Average Frequency (Number of time pressure was applied in one minute)					Average Temperature (Celsius)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	31.64					27.83					36.54				
2	29.18	25.42				26.14	28.14				37.22	36.68			
3	31.56	26.85	28.77			32.01	27.15	34.88			37.05	37.44	37.21		
4	27.95	34.75	30.12	27.56		24.1	24.46	23.75	21.77		36.71	36.96	37.21	37.01	
5	32.5	33.0	29.3	27.7	27.0	26.6	28.4	28.6	21.1	25.5	37.2	37.3	37.0	37.4	37.2

tiredness is considered to provide a reliable evaluation.

V. Analysis and Results

Table I shows us the data recorded from an eight-year-old child exercised oral therapy with our tool at different time intervals. The table presents the results of the prototype that calculated average pressure, frequency, temperature for every minute in each session. Ideally, the sensors and NodeMCU would collect and compute all of the data above, then pack them into a packet and send it to the Cloud API through Wi-Fi under the TCP/IP API. The time it takes to transfer each data packet to the cloud might vary. However, as the average Internet upload speed in the U.S is 40.28 Mbps over fixed broadband and 9.90 Mbps over mobile [39], the upload rate will have a delay of only about 0.7 seconds to compute, upload, and display the data in the database or other mobile devices. We used 25/10 (download 25 Mbps, upload 10 Mbps) and 300/180 Mbps (download 300 Mbps, upload 180 Mbps) speed in shared Wi-Fi networks to test the communication speed. To obtain credible results, we evaluated the delay time at different time during the day. The average delay which we observed in the prototype is 0.93 seconds.

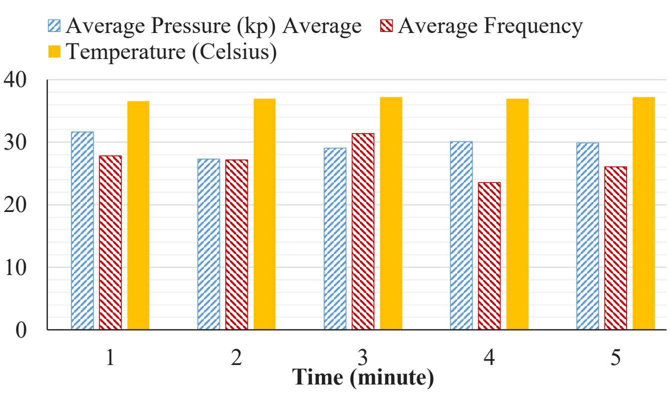

Fig. 7: The average results for each session duration splitting the session to minute.

Fig. 7 shows the average results which are obtained from the tool for 1 to 5 minutes of testing sessions. Although the average pressure amount and the frequency of activities which obtained are helpful for overall session effectiveness, the observed results are not helpful for the session itself. Since such patient loses their attention, it is not possible to understand how long the patient can focus from the session based average results. Therefore, our developed tool provide not only session average but also each minute average as shown in Table I.

In Table I, the results which are obtained from the tool are presented for 1 to 5 minutes of testing sessions. The average pressure and the number of pressing frequencies are also measured for each minute although the testing sessions are longer than one minute. As explained in Algorithm 1, patients can get tired because of the activity. Therefore, the pressure and speed can decrease in each minute. Such changes can be more obvious when the session duration is increased. For example, for this eight-year-old child, 5 minutes session shows slightly tiredness because the average pressure and the number of time pressure applied slightly decrease. Moreover, the same strategy can be used to find the attention time for the patients to arrange the session duration for the activity.

VI. Conclusion and Future Works

In this paper, we have developed a prototype speech and feeding therapy tool to easily monitor and track the progress of the patients. The proof of concept model is completed and tested in the cloud API under various network environments. We also test the device for different time intervals during the day to test its stability and reliability. The value of this project is not just the concept but also its practical and economic aspects. Besides buying a NodeMCU for just $5 and all other sensors for only $4, all the software and library we are using for this project is available online, and they are completely free and works consistently. While there have been some similar products in the market, none of them are IoT integrated. Nevertheless, the cost to replace and repairs those tools is quite high currently since there are only a few companies that produce them. Furthermore, since none of those products are integrated with IoT features, we cannot instantly keep track of the progress and effects of those therapy activities on children. Therefore, the developed tool and applications will help the parents and doctors to assess and follow the patients easily and effectively.

Although the developed tool and application have many benefits, there are relatively few disadvantages of the device. The biggest disadvantage right now is security issue [40]. Since all the patients' collected data are uploaded to the cloud database, if there is no proper secure encryption on the transmission line and database, that information can potentially be compromised and leaked. Another disadvantage is in some cases, the sensors might need to be re-calibrated after being used for a while [41]. We are working on a program that can re-calibrate every time the users restart the device to ensure that the sensors are monitoring accurately. Also, with the size of the device being only about 6 inches, sometimes, it is hard to tell if the device is out of battery or the patient is out of cellular range. Therefore, we are also developing a functionality in the application. Testing is also an essential part of this project. After addressing those problems, we will test the prototype for various conditions such as user experience, reliability, durability.

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