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Development of a portable and inexpensive tongue pressure measurement device

Desenvolvimento de um dispositivo portátil e de baixo-custo para medição da pressão da língua

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ABSTRACT

Tongue pressure measurement is highly indicated to evaluate and treat patients with reduced tongue strength, especially in the context of myofunctional therapy. However, commercially available devices are expensive. The present study describes the development of a portable, low-cost device based on the ESP-WROM-32 microcontroller to measure the pressure produced by the human tongue during myofunctional therapy. The proposed device has a current cost of US$49.00, with a resolution of 0.025 kPa, an uncertainty of ±1% Vsf making it suitable for clinical or home use.

Keywords: Lingual pressure; Myofunctional therapy; Speech therapy

RESUMO

A medição da pressão da língua é altamente indicada para avaliar e tratar pacientes com redução da força da língua, especialmente no contexto da terapia miofuncional. Entretanto, os dispositivos disponíveis comercialmente possuem elevado custo. O presente estudo apresenta as etapas do desenvolvimento de um dispositivo portátil e de baixo custo baseado no microcontrolador ESP-WROM-32 para realizar a medição da pressão produzida pela língua humana durante a realização da terapia miofuncional. Sendo que o dispositivo proposto apresenta um custo atual de $49,00, resolução de 0,025 kPa, incerteza de ±1% V_{sf} tornando-o adequado para uso clínico e doméstico.

Palavras-chave: Pressão da língua; Terapia miofuncional; Fonoaudiologia

1 INTRODUCTION

The tongue serves crucial functions in speech, breathing, mastication, and the swallowing reflex. Subjects with dysphagia (Sakamoto et al., 2022) and obstructive sleep apnea (O'connor-Reina et al., 2020) may exhibit lower tongue pressure. Therefore, the tongue pressure assessment is important in clinical speech therapy practice, particularly in the context of myofunctional therapy.

The assessment of pressure generated by the human tongue can be performed using various devices such as extensometers, pressure sensing resistors, air bulbs, and palatal plates. However, the use of different techniques makes it challenging to compare results across studies due to variations in factors such as tongue protrusion, contact point between the tongue and the sensor, and oral cavity aperture (Furlan et al., 2011).

The two main methods for measuring tongue pressure are palatal plates and air bulbs, each with distinct advantages and disadvantages. Palatal plates allow for assessment of pressure during normal activities such as articulation and swallowing (Sardini; Sepelloni and Fiorentini, 2013). A pressure sensor or pressure sensing resistor can be fixed onto the plate to measure pressure. However, the mouthpiece must be custom-made for each patient, which increases the cost and reduces accessibility to the treatment (Furlan et al., 2012).

The air bulb is made of flexible plastic material, has a spherical or cylindrical shape and are favored in clinical use due to its low-cost and disposability (Furlan et al., 2012), usually a pressure sensor or pressure transducer is connected to the end of the bulb to measure the pressure variation inside it, caused by the contact of the tongue in the bulb (Utanohara et al., 2008). But the main disadvantage associated with the use of this method is the low reproducibility of its position in the oral cavity due to the slippery nature of material used (Furlan et al., 2012).

Considering the need to assess oral functions accurately and consistently, it is relevant to mention the existence of the Iowa Oral Performance Instrument (IOPI) as one of the widely used devices for measuring tongue pressure (O'connor-Reina et al., 2023). It was developed with an amplifier that digitally displays pressures in kilopascals (kPa) and a bulb-shaped pressure sensor. This tongue bulb pressure sensor is commonly used to measure tongue force due to its portability, pressure detection circuit, peak retention function, and IOPI timing features (Plaza; Busanello-Stella, 2023).

Although the IOPI has proven to be a suitable and effective tool, demonstrating strong reliability (Adams et al., 2013), some authors have reported that it has high costs for home use, requiring various connecting components and air-filled bulbs that are prone to leaks, while material properties may change with use and deformation (Hewitt et al., 2007). This issue highlights the importance of seeking alternatives that offer a more reliable and simplified approach to perform these measurements. In this context, the development of a device for measuring tongue muscle pressure underscores the relevance of work in the quest for innovative solutions to improve conditions, such as dysphagia and obstructive sleep apnea that require myofunctional therapy.

Therefore, the aim of this study is to describe the development of a novel portable and low-cost device that uses a plastic air balloon to measure the pressure produced by the tongue.

2 MATERIALS AND METHODS

A measuring device can be divided into three fundamental modules, the first one being the sensor or transducer that modifies its own electric output signal upon change in the measured. Furthermore, the second stage can be defined as the signal processing unit where the signal is filtered, amplified and converted. Therefore, the third module encompasses the data acquisition by a controller and its exposition to the user (Beckwith; Marangoni; Lienhard, 2011)

Thus, each stage of the device must be dimensioned according to the physical phenomenon that it will be measuring to, in this way, minimize the buildup of error from the combination of different components in the system.

2.1 Tongue maximum pressure

Prandini et al. (2015) reported that the maximum pressure in tongue elevation and tongue protrusion for adult males, measured with the Iowa Oral Performance Instrument, is 63.94±12.92 kPa and 60.22±13.62 kPa, respectively. These values are consistent with the mean values described in the instrument user manual. Utanohara et al. (2008) reported a peak pressure of 41.7±9.7 kPa in tongue elevation using their own manufactured air bulb and instrument. Liu et al. (2021) presented a result of 41.31±13.63 kPa for tongue elevation using their novel mouthpiece technology.

While there is divergence in peak pressure values reported in the literature, this can be attributed to differences in measurement methodologies. For design purposes, the device must be able to assess pressure in the upper range of pressures produced by the tongue. Thus, for this purpose, the maximum value will be considered to be within the range of 63.94±12.92 kPa, as suggested by Prandini et al. (2015).

2.2 Device dimensioning

For the development of a device capable of measuring tongue pressure in myofunctional isometric exercises, it is essential to take into consideration, in the dimensioning of the instrument, an adequate sampling rate. Due to this fact, the sampling rate in isometric exercises can be as low as 62.5 Hz, since at this frequency the device is able to capture sufficient details in the proposed exercise with an error of less than 2% (Hewitt et al., 2007).

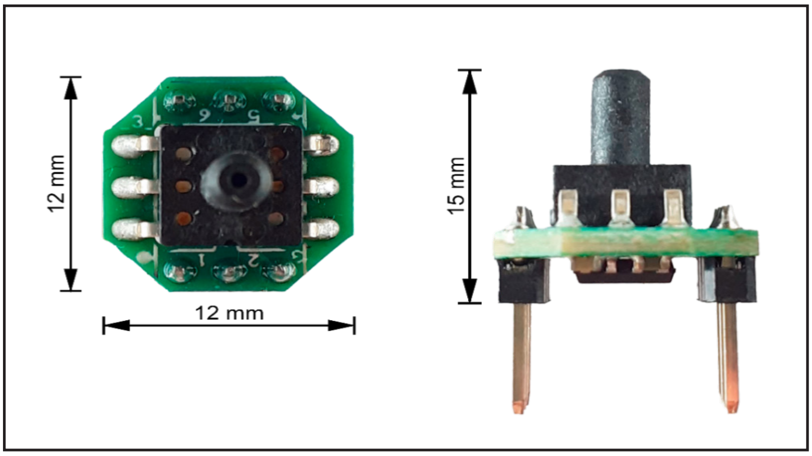
Another essential characteristic to take into consideration is the peak pressure that the human tongue can generate. Since the aforementioned is considered to be 63.94±12.92 kPa the pressure sensor used in the device must be capable of measuring the range described with a sampling rate higher than 62.5 Hz.

Considering that the instrument is designed for clinical and domestic use, the electronic components must be small and easily accessible to guarantee the low-cost and portability of the device and the receptiveness of the myofunctional therapy.

2.2.1 Device components

To comply with the device requirements, a piezoresistive pressure sensor of model XGZP6847100KPG, Figure 2, was chosen due to its measuring range of 0 to 100 kPa and response time of 2 ms adequate to a sampling rate of 500 Hz, furthermore, the chosen sensor is linear, stable and factory calibrated (CFSensor, 2019).

Figure 2 – Top and lateral view of the pressure sensor



Source: CFSensor (2019)

It is valid to mention that the sensor output voltage variation can be linearly related to the pressure in the 0 to 100 kPa range, according to the Equation 1 (CFSensor, 2019).

$$pressure = 0.025 \cdot output\ voltage - 12{,}5\ kPa \quad (1)$$

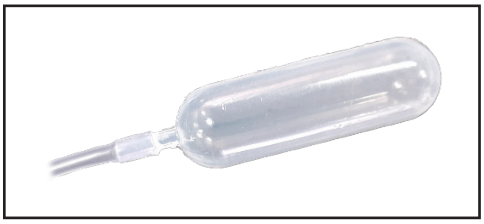
Whereas, the *pressure* is a first-degree polynomial function dependent on the output voltage change in mV.

For the data acquisition, an ESP-WROM-32 devkit module was used due to its capabilities in internally processing data and transmitting it via the Bluetooth interface (Espressif Systems, 2023), rendering the proposed device portable as the data can be viewed and analyzed on smartphones and computers without the use of cables.

Due to the fact that the output analog signal of the pressure sensor ranges from 0.5 V to 4.5 V and the ESP32 module has a limit of 3.3 V in its input pins, it is necessary to perform the signal discretization in an external module to pick up the entire signal range of the sensor. Thus, a 16-bit analogic to digital converter (ADS1115) was used considering its 860 Hz sampling rate and resolution of 0.1875 mV (0.025 kPa) over a 5 V supply (Texas Instruments, 2018).

The selected method for tongue pressure assessment was the air bulb due to its ease of use and possibility of sterilization and disposal, making it ideal for clinical and domestic use. Therefore, the chosen air bulb is manufacture by the Brazilian company *Pró-Fono*, Figure 3, and was used because of its low cost and high availability.

Figure 3 – Plastic air bulb used in the proposed device



Source: Pró-Fono (2024)

Thus, the air-filled plastic bulb is connected by 3 mm flexible tubbing to the pressure sensor and is positioned inside the patient’s mouth in accordance with the health professional orientation during clinical and domestic use to assess the progress of the myofunctional treatment by measuring the tongue pressure in isotonic and isometric exercises.

2.2.2 Measurement uncertainty and resolution

For the 16-bit analog to digital converter voltage signal input range of 0.5 to 4.5V from the pressure sensor, the resolution is 0.1875 mV (Texas Instruments, 2018), or 0.025 kPa according to equation 1, which constitutes the device resolution. Furthermore, for a temperature range of -30°C to 100°C, the sensor uncertainty is from ±1%Vsf (CFSensor, 2019).

2.2.3 Bill of materials

The materials used during the manufacturing of the proposed pressure measuring device are listed as follows, with their costs in dollars

Table 1 – Bill of materials

Item	Cost in January 2024 (dollars)
ESP32 devkit module	$8.00
100 kPa pressure sensor	$8.00
Air bulb	$4.00
5x Electrolytic capacitors (100 µF)	$1.00
6x Ceramic capacitors (100 ηF)	$1.00
Fixed voltage regulator (L7805CV)	$1.00
Step-up voltage regulator (MT3608)	$2.00
3,7V LiPo battery (1800 mA)	$12.00
LiPo Battery charger (TP4056)	$3.00
Analog to digital converter (ADS1115)	$9.00
Total	$ 49.00

Source: Authorship (2024)

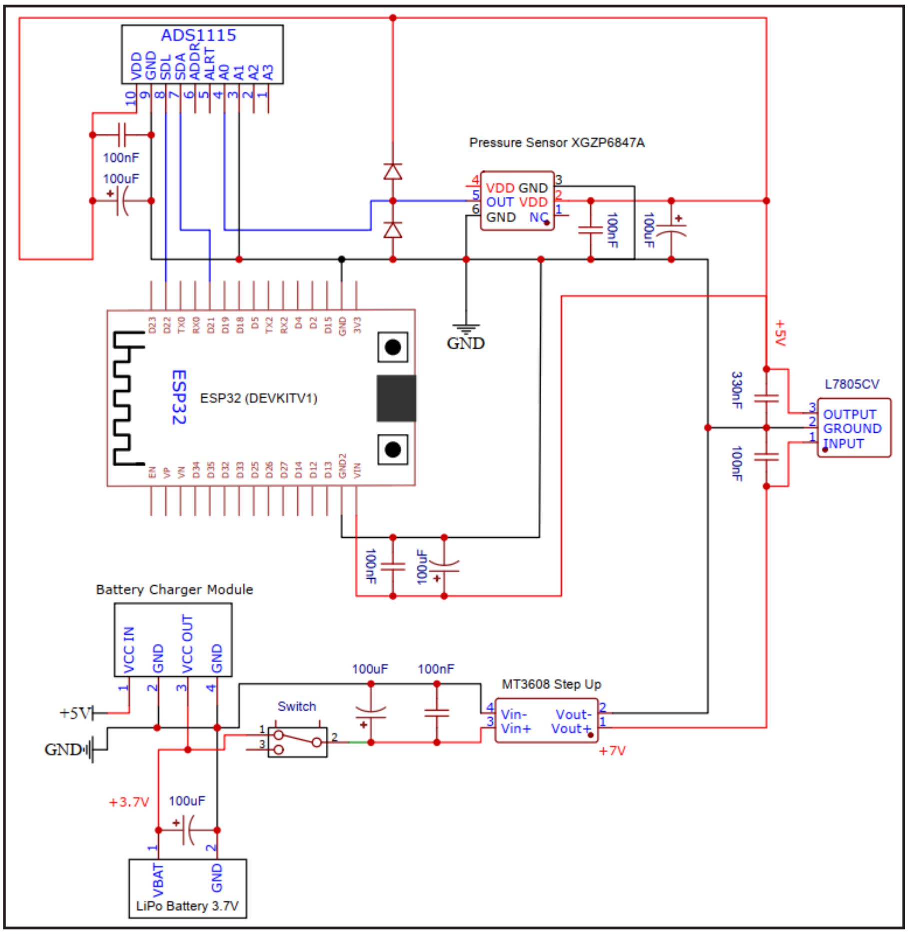
Therefore, the total cost of the proposed device is of $49 dollars, which fulfills the requirement of being low-cost to make myofunctional therapy more accessible for the general population and be applied in clinal or domestic use.

2.3 Device manufacturing

The first step in the device manufacturing was the design of the electrical circuit, as shown in Figure 4, with the software *EasyEDA.*

In order to reduce the noise of the power supply in the measuring system, decoupling capacitors are used. Thus, ceramic capacitors were placed close to the power input of each module to minimize high frequency oscillation and magnetic induction phenomena, while electrolytic capacitors were utilized to reduce low frequency oscillation that disturbs the measurement (Texas Instruments, 2019).

Figure 4 – Electrical diagram of the measuring system

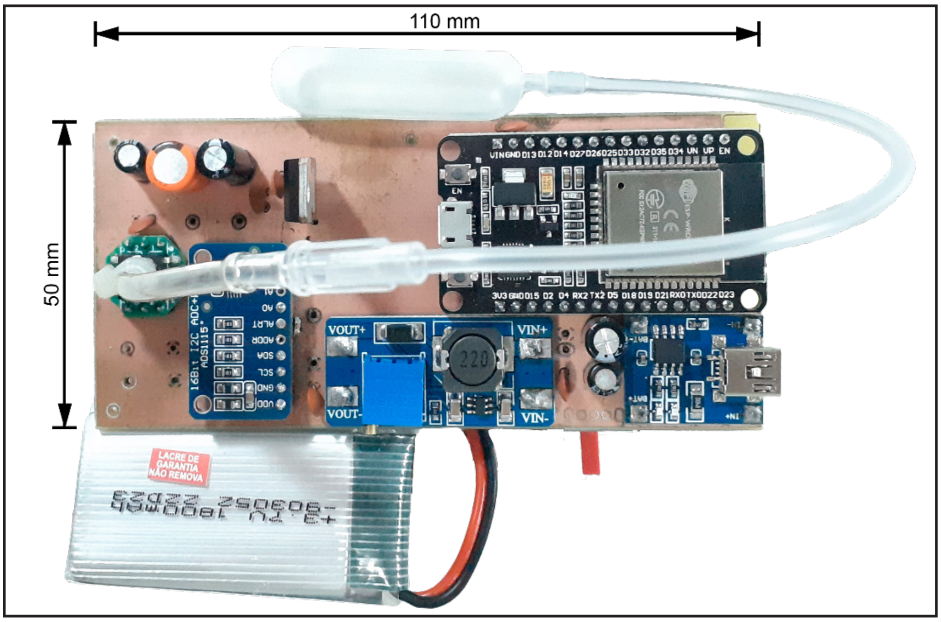


Source: Authors (2024)

Moreover, Zenner diodes are used as electrostatic protection (Toshiba, 2022) in the output of the pressure sensor as per the recommendation of the manufacturer (CFSensor, 2019).

Thus, a printed circuit board (PCB) was designed and printed in accordance with the electrical diagram in Figure 4 and it is shown in Figure 5.

Figure 5 – Device PCB



Source: Authors (2024)

3 RESULTS AND DISCUSSION

The measurement uncertainty of the proposed device was assessed through the use of a vise with a semi cylindrical plastic attachment to equally distribute the force, considering that the pressure in the experiment can be fixed by locking the vise's screw. Therefore, the stability of the proposed device was assessed through the standard deviation of the measured values.

Thus, for ten different pressures in the range of 0 to 100 kPa, 100 values were measured, and the standard deviation was calculated, as shown in Table 2.

Therefore, the uncertainty of the proposed device is in accordance with the data from the pressure sensor manufacture, since the measured uncertainty is below the ±1% described by the pressure sensor's manufacturer (CFSensor, 2019).

Table 2 – Measured uncertainty for ten fixed pressure values

Fixed pressure value	Average measured value	Uncertainty
10 kPa	9.97 ±0.022 kPa	±0.23%
20 kPa	19.99 ±0.013 kPa	±0.07%
30 kPa	29.96 ±0.017 kPa	±0.06%
40 kPa	40.00 ±0.022 kPa	±0.06%
50 kPa	49.98 ±0.026 kPa	±0.05 %
60 kPa	59.99 ±0.039 kPa	±0.06%
70 kPa	70.00 ±0.032 kPa	±0.05%
80 kPa	80.00 ±0.070 kPa	±0.09%
90 kPa	89.93 ±0.031 kPa	±0.04%
100 kPa	99.79 ±0.14 kPa	±0.14%

Source: Authorship (2024)

Thereby, the proposed device meets all the established criteria since it has a low-cost, small components that are easily accessible, rendering the device portable, its resolution and sampling rate are adequate to assess the measurand and the air bulb used can be sanitized or discarded, making it suitable for clinical and domestic use.

4 CONCLUSIONS

This study describes the development of a new device that utilizes a plastic air balloon to measure the pressure generated by the tongue during myofunctional therapy for both clinical and home use. The objective of this work was achieved as the manufactured device is portable, low-cost, and has satisfactory resolution and stability. However, additional studies are required to validate the use of the device in clinical trials and compare its measurements with those of commercially available devices.

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