ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at: www.ijdsir.com

Volume – 5, Issue – 4, August - 2022, Page No. : 209 - 215

Novel-Miniature Digital Gauge for Analysing Dentoforce

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Citation of this Article: Dr. Mir Shahid Ulla, Dr. Pradeep Chandra K, Dr. Smitha Sharan, Dr. Sarandha D L, Dr. Sreeharsha T.V, Dr. Brunda K, "Novel-Miniature Digital Gauge for Analysing Dentoforce", IJDSIR- August - 2022, Vol. – 5, Issue - 4, P. No. 209 – 215.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

This paper presents the design and development of a low cost and reliable maximal voluntary bite force measurement device which can be manufactured in-house by using an Arduino Nano and flexi force sensor with chief advantage of it being portable which can be delivered to the patient, store the readings in the SD card as well as OTA display of forces. The device has been designed for ease of fabrication, assembly, calibration, and safe use. The device is capable of use within an hour of commencing production, allowing for rapid proto typing/ modifications and practical implementation. The measured data shows a good linear relationship between the applied force and the electrical resistance of the sensor. The output signal has low drift, excellent repeatability, and a large measurable range of 0 to 800 N. A high signal-to-noise response to human bite forces was observed, indicating the high potential of the proposed sensor for human bite force measurement.

Keywords: bite force; fsr; flexi force; Arduino; oral health

Introduction

The maximum bite force (MBF) and maximal voluntary bite force (MVBF) of the human jaw can correlate to the wellbeing and oral health of the patient [1–4]. The literature in this field of study indicates a number of research studies being performed on the relation to or measurement of human and animal bite forces [2,5–9]. For example, MBF has been used to verify the connection between the poor dental health of children and the impact it can have on their quality of life [2]. Bite force has also been employed as an indicator for patients with bruxism, where the patient is able to wear a prescription splint to sleep that has an integrated sensor and circuit to record and relay important information on the patient's jaw activity while sleeping [6]. Furthermore, an oral occlusion measurement system can give dentists the ability to perform a full analysis on the occlusion of their patients upper and lower jaws, where MBF measurements are only a part of the occlusion measurement process [10]. As such, a full occlusive analysis can be used for assisting in dental rehabilitation through implants and or prosthetics [11].

Finite element analysis (FEA) of a patients' mouth can be performed using a scanned model of the patient's teeth and jaw, which presents a potential MBF under various assumptions.

However, FEA is not quantifiable as a MVBF since it often tests the physical limits of the size and estimated mass of the patient's teeth [12], and does not take into account other anatomical structures such as periodontal ligaments and the natural flex of the mandible [13]. Moreover, MVBF measurements can be performed locally in the patient's mouth and requires physical exertion on the sensor involved. Many factors have an impact on the measured MVBF, such as the position of the device when taking measurements, the opening of the mouth, and the effect of unilateral and bilateral biting. In theory, the highest reading would be taken using a bilateral device positioned at the rear molars [14]. Both unilateral and bilateral in vivo tests are commonly performed in many studies.

To date, there have been a large number of sensors developed to measure a patient's bite force or MVBF. One such example is T-Scan—a commercially available system which uses a pressure sensitive sheet sensor that is capable of assisting dentists perform a full occlusive analysis on their patients. However, the cost of the T-Scan system is relatively expensive, especially when full occlusive analysis is not necessary. This system has been tested and validated in [10], and has been used by dentists in real-world applications. Another method uses Flexi Force, which is a thin and flexible printed circuit used in force measurements from Tek Scan Inc. [15]. Flexi Force and Force Sensing Resistors have been used in the very accurate measurement of bite forces in both humans and animals alike [9,18–20]. The bite force range generally falls within 0 to 700 N which is suitable for taking MVBF measurements.

This paper presents the design, fabrication, and characterization of a novel bite force measurement device based on the application of Flexi Force sensors and Arduino Nano. The proposed sensor possesses a flexible structure, which can be easily obtained from Interlink Electronics, (Model A401).

The main highlights of it being portable, which can be delivered to the patient, storage of readings in the SD card as well as OTA display of forces makes it unique in its field. The proposed sensor is capable of measuring a large bite force range of up to 800 N with high repeatability, and good linearity. We have also successfully demonstrated the use of the sensor for accurate real-time measurement of human bite forces. These results indicate our proposed sensors' significance for ubiquitous bite force sensing applications.

Design and Simulation

As mentioned in the introduction, the developed bite measurement device should be capable of measuring forces ranging from 0 to 800 N. The used bite force sensor had the following major components: an inner sensor, an intermediate activator and an outer surface. The inner sensor was made of a circular conductive polymer pressure-sensing resistor (FSR no. A401 NF, Interlink Electronics, Echternach, Luxembourg). It had a diameter of 12 mm and a thickness of 0.23 mm, and consisted of two conducting interdigitated electrodes deposited on a thermoplastic sheet which in its turn faced a second sheet coated with a semi conductive polyetherimide ink (Fig. 1). These two sheets were separated by a spacer that increased the peripheral thickness of the sensor to 0.3 mm (Fig. 2). Its basic characteristics were piezoresistive, i.e., its resistance decreased with increasing normal pressure [26,31]. The thermoplastic sheets also insulated the sensor that protected it from moisture and reduced the effects of temperature changes. Force sensing resistors have been reported to present a temperature drift of —0.3%/°C.

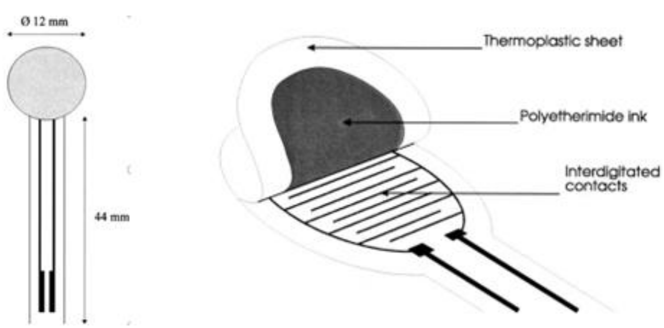

Figure 1: Sensor design. (a) Dimensions. (b) Cross-sectional view of the proposed sensor.

Next, Arduino nano was used to design an electrical circuit. The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328P (Arduino Nano 3.x).

The SD card module is especially useful for projects that require data logging.

The Arduino can create a file in an SD card to write and save data using the SD library. Node MCU is an open source LUA based firmware developed for ESP8266 Wi-Fi chip. Node MCU Development board is featured with Wi-Fi capability, analog pin, digital pins and serial communication protocols.

Real time clocks (RTC), as the name recommends are clock modules. They are available as integrated circuits (ICs) and supervise timing like a clock and also operate date like a calendar.

The main advantage of RTC is that they have an arrangement of battery backup which keeps the clock/calendar running even if there is power failure.

Arduino software was used to program, Arduino Integrated Development Environment (IDE), Arduino IDE is a special software running on your system that allows you to write sketches (synonym for program in Arduino language) for different Arduino boards. The Arduino programming language is based on a very simple hardware programming language called processing, which is similar to the C language.

After the sketch is written in the Arduino IDE, it should be uploaded on the Arduino board for execution.

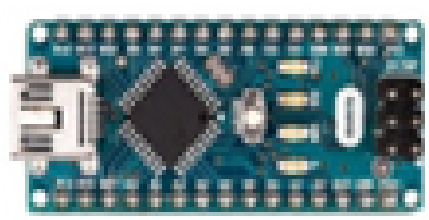

Figure 1: Arduino Nano

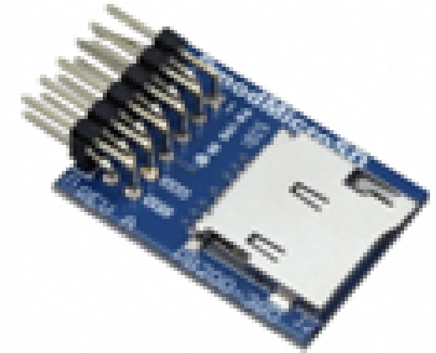

Figure 2: SD Card Module

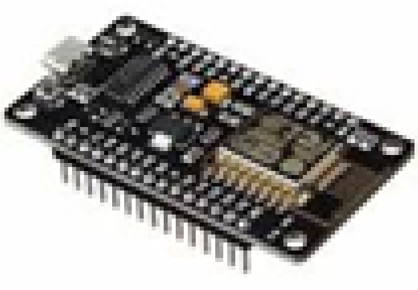

Figure 3: Node MCU

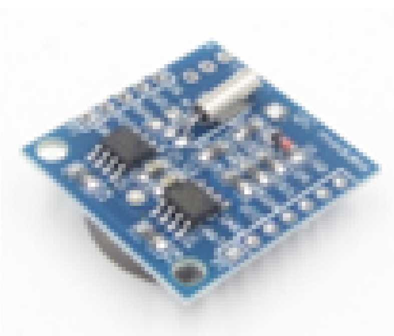

Figure 4: Real Time Clock Module

Circuit connections were made following the instructions from the Arduino sketchbook for the SD card module, node MCU, RTC and FSR using connector pins. Following this, the Arduino was powered and programmed to read data from FSR and store in SD card and at the same time transmit the data over the air (ada fruit platform) to be viewed from anywhere.

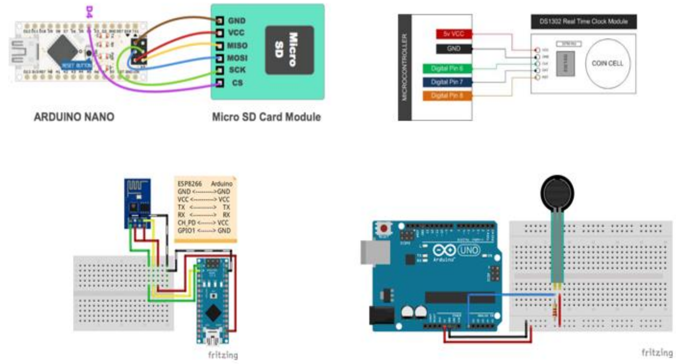

Figure 5:

In Vitro Experimental Validation

For practical testing, typhodont teeth sets were used and the sensor was positioned under their second molar and make three consecutive attempts to bite as hard as they could.

Figure 6: Position and orientation of sensor in practical testing.

These values all fell within the expected values of MVBF readings. It is worth noting that the responses of the sensor to human bite forces is with a high signal-to-noise ratio. This indicates that the sensor can be used for highly sensitive monitoring of oral status.

In addition, the gradual increase in force for the first bite of each subject was observed indicating a common tendency of the subjects to first get a feel for the bite force sensor before making further attempts. The results all exhibit evidence for a good performance of the novel bite force sensor which may find applications in oral status monitoring and other healthcare applications.

Conclusions

In conclusion, the results presented herein demonstrate the simple and user-friendly fabrication of a novel, economical bite force The sensors showed good linearity and excellent repeatability with the capability of measuring a large bite force range of up to 700 N. The successful demonstration of the measurement of human bite force in real-time indicates good feasibility for using this novel sensor for personal healthcare applications.

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