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Internet of Things Platform for Real-Time Intraoral Forces Monitoring

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Abstract

In the Internet of Things era, medical devices shall be miniaturized and connectable to the global network for exchanging patient data. In this work, the miniaturization of a device for wireless intraoral forces monitoring is presented. Strain gauges are used as force sensors detecting tongue and lips activities.
Signal elaboration has been demanded to an STM32NUCLEO-F401RE board while wireless data transmission using Bluetooth® Low Energy standard protocol is obtained by means of a XNUCLEO-IDB04A1 board. The circuit has been further miniaturized using a SoC based on Nordic nRF51422 that features an ANT and Bluetooth® low energy transmission and an ARM Cortex-M0 core.
The final device shows a reduced dimension and the ability to transmit data wirelessly, without the use of external cables normally used in state-of-the-art intraoral monitoring devices.

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Keywords: Intraoral force monitoring; wireless sensor; Internet of things

1. Introduction

Information on intraoral forces provides dentists and maxillofacial surgery doctors useful data for monitoring dental and occlusal diseases, evaluating the functional status of the masticatory system and comparing alternative treatments in post-surgical evolution [1–3].

A peculiar characteristic of an Internet of Things node is the dimensions of the electronics and sensors [4-5] and the features to reduce the power consumption exploiting new design and harvesting technologies [6–10]. In fact, it must be positioned inside the mouth or in contact with a very limited surface, such as that of a tooth.

Another important feature is the resolution of the sensor, which must be able to detect forces of few grams [11], and that must be compatible with standard industrialized processes and technologies [4,12].

The last requirement for this type of device is to implement algorithms that allow to overcome the prestrain problem that affects every strain gauge sensor, which is caused by their mechanical positioning and led to an altered rest condition measurement.

This work presents the miniaturization of a device for wireless intraoral forces monitoring with the use of a SoC based on Nordic nRF51422 and Bluetooth® low energy wireless transmission, which, coupled with a smartphone application, allows you to monitor the intraoral forces.

2. System Description

In a first approach of the problem, as shown in Fig.1, the system was composed by 3 major sub-systems:

• Sensors: the sensors used have been identified as an outcome of an analysis of the state-of-the-art literature [4], determining the model 015LW by VPG Inc. (Fig. 2), a 120 Ω strain gauge with sizes of 1.90 x 1.37 mm, as the favorable candidate for the usage in the intraoral environment.

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• Sensor conditioning: this block is based on the MaxLinear XR10910 IC, a sensor interface IC with 16:1 differential analog multiplexer, that allows to interface multiple bridge sensors to a single analog-digital converter. It connects the output of one of the bridges to a programmable gain amplifier (PGA) with offset regulation. This block was designed and prototyped as a PCB with a form factor of 2 x 1 cm, as shown in Fig. 3.

• Elaboration and transmission: a STM32NUCLEO-F401RE by STMicroelectronics was used both to acquire the analog signal coming from the sensor interface IC and to transfer the settings using I2C protocol. A XNUCLEO-IDB04A1 shield allows the connection with a hub or external smartphone application via Bluetooth protocol. The Bluetooth was selected for the characteristics of extreme low power consumption required by the protocol and the reduced size of the module. The prestrain problem is compensated and overcome by dynamically generating an offset voltage added to the sensor signal, equal and opposite to that generated by the effect of the prestrain.

The prototype of the entire system is shown in Fig. 4.

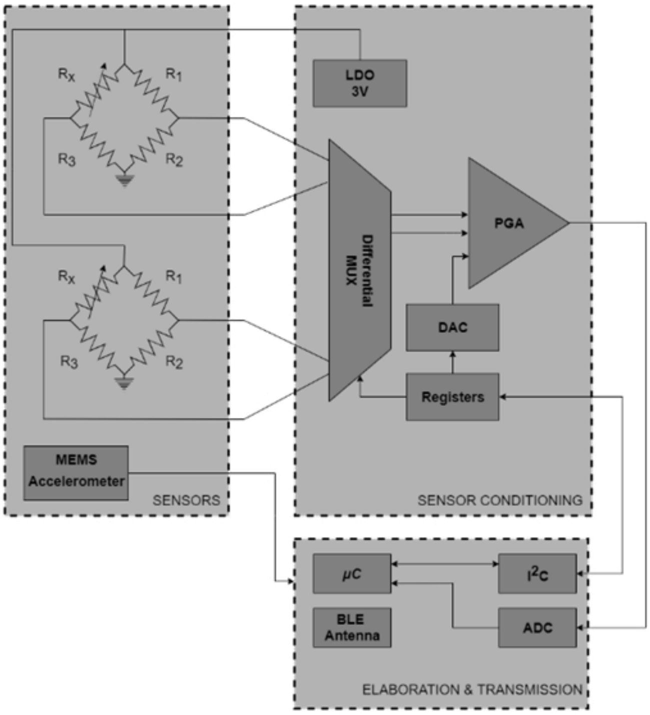

Fig. 1. Block diagram of the prototype

Fig. 2. 015LW by VPG Inc

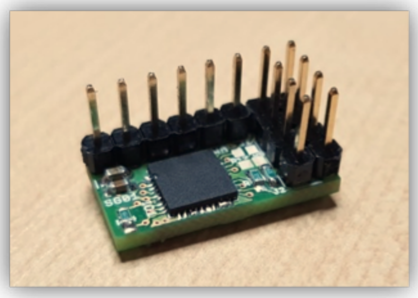

Fig. 3. First prototype that implements the Sensor Conditioning block

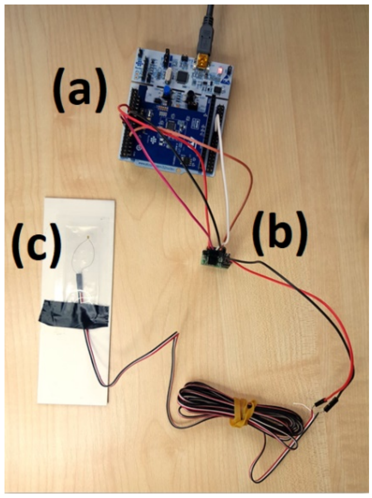

Fig. 4. Prototype implementation of the entire system. NUCLEO-F401RE with IDB04A1 mounted on top (a), custom PCB that implements the Sensor conditioning block (b) and the strain gauge sensor 015LW (c)

The voltage VOUT acquired by the ADC of the microcontroller can be used to calculate the variation of the resistance ΔR, which is proportional to the force applied to the sensor, as shown below:

$$\Delta R = R\,\frac{4\,(V_{OUT} - 1.5) \mp 4\,G\,V_{DAC}}{G\,V_{BRDG} - 2(V_{OUT} - 1.5) \pm 2\,G}$$

where:
R is the nominal value of the sensors resistance (R=R1=R2=R3) and the bridge resistors, VBRDG is the supply voltage of the bridges (3V), G is the gain selected for the PGA, VDAC is the value of the offset correction DAC, ΔR=RX-R.

The measurements can be transferred to a smartphone using the Bluetooth connection, where they are received using an application specifically designed for the purpose. The application allows the user to select the sensor, and display the raw or elaborated data; a screen-shot of the application is showed in Fig. 5.

3. Miniaturization

The solution has been miniaturized in order to be integrated in an intraoral appliance. With the aim of creating a completely wireless and size constrained system, a custom circuit with a dimension of 2x1 cm was conceived, designed and prototyped.

The circuit, shown in Fig. 6, has been developed using the EYAGJNZXX SoC by Taiyo Yuden SoC based on Nordic Semiconductor nRF51422; it features an ANT and Bluetooth® low energy transmission and an ARM Cortex-M0 core. The system includes the MaxLinear XR10910 sensor interface IC already described in paragraph 2, and a power conditioning stage with a DC/DC boost converter that allows to supply the entire system from a 1.5 V miniature coin battery source.

The circuit will be coated using an EPO-TEK® MED-301 biocompatible epoxy from Epoxy Technology Inc. to be used inside human mouth.

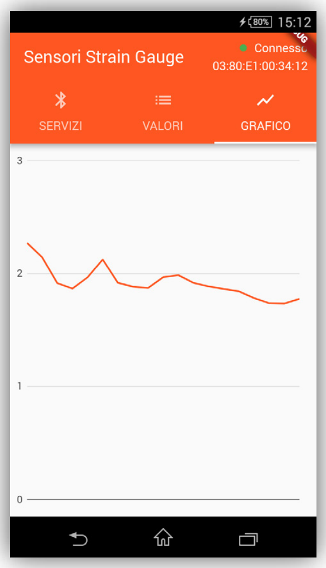

Fig. 5. Graphic representation of VOUT values inside the custom realized smartphone app.

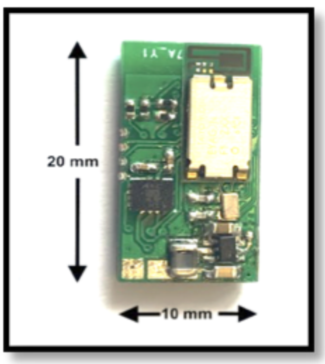

Fig. 6. PCB Overview

4. Experimental analysis

The small dimensions of the sensor cause a reduced variation of its resistance, requiring a high amplification value of the integrated programmable gain amplifier, up to 760 V/V. Within this condition, prestrain [13-15] could saturate the output preventing a proper measurements of the forces detected by the strain gauges (Fig. 7a). A software routine has been designed to adjust the offset voltage added to the sensor signal, to dynamically compensate for prestrain issues. Fig. 7b shows the signal corrected with the calibration algorithm applied.

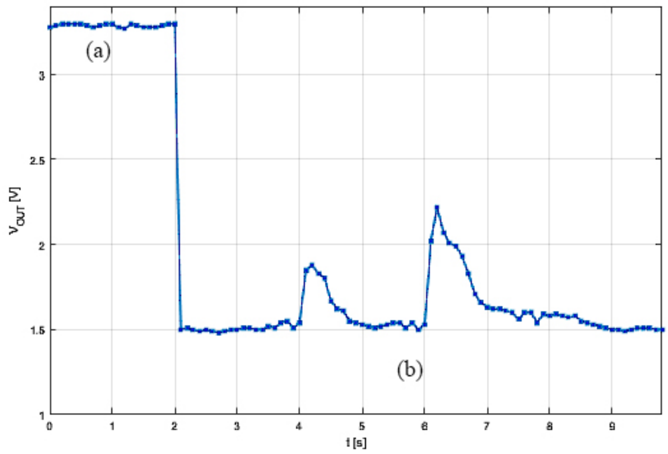

Fig. 7. Saturation of the output (a) and prestrain overcome (b). Voltage output of the Signal Conditioning Block after offset addition

5. Conclusions

The work describes the realization and miniaturization of a IoT device for wireless intraoral forces monitoring which uses strain gauges as force sensors to detect tongue and lips activities. The device has a reduced form factor for use in the oral cavity, and the ability to transmit data wirelessly with Bluetooth Low Energy protocol. A companion application has also been realized to acquire the data from the sensors.

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