Wireless Sensors for Intraoral Force Monitoring

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Abstract. A device for wireless intraoral forces monitoring is presented. Miniaturized strain gauge sensors are used for the measurements of forces applied by tongue and lips. A sensor interface IC is able to multiplex among four sensors and a low energy transmission module, equipped with an ARM Cortex–M0 core, is used for signal elaboration and remote wireless data transmission using Bluetooth® Low Energy standard protocol. The main novelty rely in the dynamic correction of the output corrupted by the prestrain issue. Moreover, the 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.

1 Introduction

In the fields of odontology and maxillofacial surgery, information about intraoral forces could be used for monitoring of dental and occlusal pathologies, for judging the functional state of the masticatory system and for the comparison of alternative treatments in post-surgical evolution [1 - 3].
A peculiar characteristic of a sensor for monitoring intraoral forces is, clearly, the dimensions [4]. In fact, it must be either positioned inside the mouth or in contact with a very limited surface, such as that of the tooth.
Another characteristic is the resolution of the sensor, which must detect forces of few grams [5]. Sensors should be compatible with standard CMOS technology or industrialized processes [4, 6 -8].
Last requirement for this kind of device is to overcome the prestrain problem that affects every strain gauge sensor, that is caused by their mechanical placement and led to an altered rest condition.

2 System Description

With the aim of creating a completely wireless and size constrained system, a custom circuit was conceived, designed and prototyped with a form factor of 2 x 1

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cm, as shown in Fig. 1. The system will be embedded using an EPO-TEK® MED-301 biocompatible epoxy from Epoxy Technology Inc. to be used inside human mouth. The circuit consists of four main blocks (Fig. 3):

- **Sensors**: an analysis of the state-of-the-art literature and the search for the most performing electronic components available on the market [4], led us to the selection of the model 015LW by VPG Inc. (Fig. 2), a 120 Ω strain gauge with sizes of 1.90 x 1.37 mm. The sensor block also includes a MEMS accelerometer for future use.
- **Power Conditioning**: it contains the supply source regulation block and a DC/DC converter able to boost a 1.5 V coin battery source.
- **Sensor conditioning**: it contains a sensor interface IC with 16:1 differential multiplexer for interfacing multiple bridge sensors. It connects the output of one of the 4 bridges to a programmable gain amplifier (PGA). The prestrain problem is compensated and overcome by using a 10-bit DAC which dynamically generates an offset voltage added to the sensor signal, equal and opposite to that generated by the effect of the prestrain.
- **Elaboration and transmission**: The PCB host the SoC EYAGJNZXX by Taiyo Yuden, an ANT+ Bluetooth® low energy transmission module with an ARM Cortex-M0 core. This block allows the connection with a hub or external smartphone application (Fig. 4). The Bluetooth was selected for the characteristics of extreme low power consumption required by the protocol and the reduced size of the module.

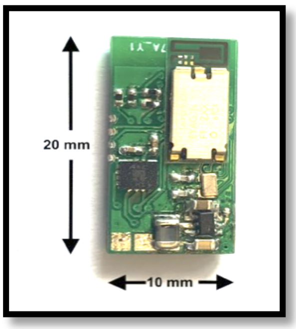


Fig. 1. PCB Overview.

Fig. 2. 015LW by VPG Inc.

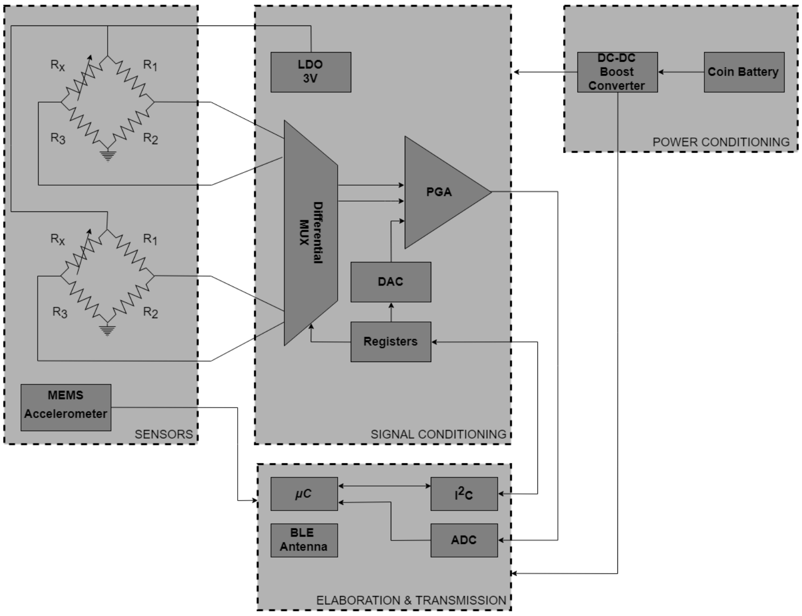


Fig. 3. Block Diagram of the system.

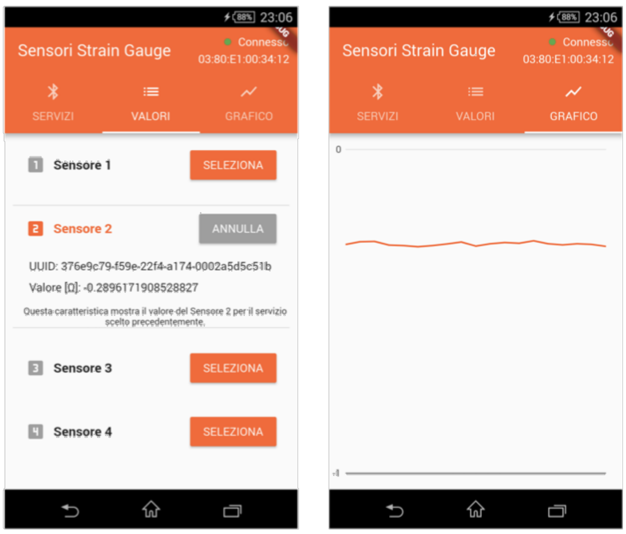


Fig. 4. Application screenshoots.

It is possible to calculate the variation of the resistance ΔR as shown below:

$$\Delta R = R[4(V_{OUT} - 1.5) \mp 4GV_{DAC}]/[GV_{BRDG} - 2(V_{OUT} - 1.5) \pm 2GV_{DAC}]. \quad (1)$$

where R is the nominal value of the sensors resistance ($R=R_1=R_2=R_3$), V_{BRDG} is the supply voltage of the bridges (3V), G is the gain of the PGA, V_{DAC} is the output of the 10-bit DAC, V_{OUT} is the value read by the ADC of the microcontroller and $\Delta R=R_x-R$.

3 Experimental analysis

Due to the high amplification value of the PGA (from 2V/V to 760V/V), prestrain [9] could saturate the output leading to a corruption of the measurements of the forces coming from the strain gauges, embedded in resin as shown in Fig. 5. With the use of a proper software routine, the DAC output is adjusted and can dynamically compensate for prestrain issues, as shown in Fig. 6.

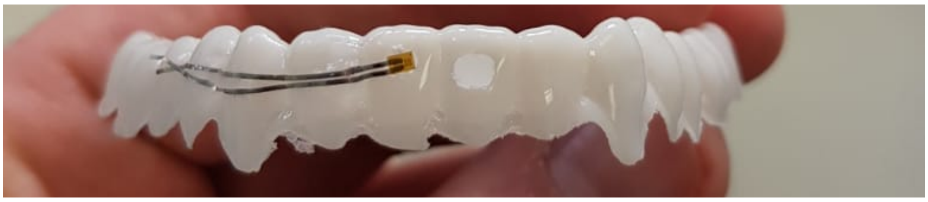
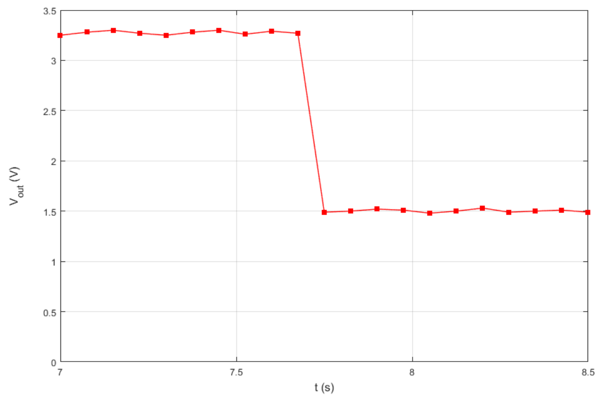
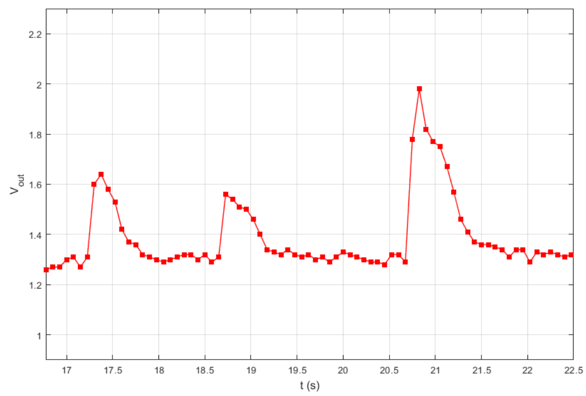


Fig. 5. Application of a strain gauge sensor in an intraoral appliance.



(a)



(b)

Fig. 6. Saturation of the output (a) and prestrain overcome (b). Voltage output of the Signal Conditioning Block after DAC offset addition.

The measurements are sent to a Smartphone using a Bluetooth connection, and showed in a custom application where the user can select, for each single sensor, to see raw or elaborated data, showed in Fig. 4.

4 Conclusions

In this work, a wireless intraoral sensor device has been proposed. It is well suited to extrapolate information about intraoral forces because of its reduced size, the use of BLE protocol instead of wire communications and the ability to dynamically compensate for prestrain issues.

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