A sensorized mat for monitoring pressure distribution

M. Donati[1], F. Cecchi[1], F. Bonaccorso[1], M. Branciforte[2], P. Dario[1], and N. Vitiello[1]
[1]The BioRobotics Institute, Scuola Superiore Sant'Anna, viale Rinaldo Piaggio 34, Pontedera (PI), 56025, Italy.
[2]ST Microelectronics, Stradale Primosole 50, Catania (CT), 95121, Italy.

***Abstract*—In this paper a performance analysis of a sensorized mat for monitoring pressure distribution through the measure of pressure maps is presented. The mat is based on an optoelectronic technology developed at Scuola Superiore Sant'Anna. The device has a modular structure which allows to vary the sensorized surface from about 0.13 m^2 (for an array of 768 pressure sensors) to about 1 m^2 (for an array of more than 4600 pressure sensors).**

***Keywords*—pressure-sensitive mat, optoelectronic pressure sensor, pressure map, pressure distribution.**

I. Introduction

PRETERM infants have higher risk of developing cognitive and motor disorders than full-term born infants [1]. In the last thirty years the concept of early intervention [2] became very important for the development of spontaneous motor activity in infants who showed disabilities [3]. Rehabilitative sessions are carried out by specialized clinicians through visual analysis of rehabilitative tasks using functional-assessment scales. The analysis of the exercise is subjected to the experience of the therapist and, therefore, a quantitative evaluation is not always easy.

In the last years several approaches were explored to introduce new parameters of infants' motor activity and coordination, to allow a more objective evaluation of patients [4],[5]. A non-intrusive method to monitor the change in the infant's posture exploits the measurement of the pressure distribution between the infant and the mat where he/she lays down during the therapy [6],[7].

In this work, we present a further quantitative experimental characterization of the sensorized mat presented in [8] by assessing its capability to recognize objects with different shape and weight.

II. Architecture

The sensorized mat is composed of two main parts: the transduction module, and the electronic module (Figure 1).

The device presents a modular structure which allows to vary the sensorized area on the basis of the rehabilitative task.

A. Transduction module

The transduction module is composed of a variable number of sub-modules, from a minimum of one (with the dimension of 31x42 cm^2) to a maximum of six (overall dimension of 93x84 cm^2). Each sub-module integrates on the top face, an array of 32x24 pressure sensors (total amount of 768 identical sensitive elements), and, on the bottom face, a layer of multiplexers converting the 768 output signals into 48 analog signals.

Each pressure sensor uses an optoelectronic transduction technology [9], and is composed of two main parts: (i) a silicone cover, which has a shell structure with a pyramidal frustum shape, with an inner vertical curtain, and (ii) a printed circuit board, which houses the optoelectronic components: the light transmitter (a high luminosity green LED) and the light receiver (an analog ambient light opto-electronic transducer with current output). When a load is applied on the top surface, the silicone cover deforms itself and the curtain gradually closes the light pathway between the emitter and the receiver, thus the output voltage changes [8].

The cover was realized in Dragon Skin 10 Medium silicone (Shore 10 A, Smooth-On Inc., Easton, PA, USA), coloured by black ink in order to be opaque with respect to the LED light. The dimension of the frustum base is 12x12 mm^2, the top face is 9x9 mm^2, and the height is 5.5 mm. The frustum base is surrounded by a frame of 1 mm of free space, which gives a final spatial resolution of 1.69 cm^2. By changing the dimension of the pyramidal frustum, and/or the silicone, it is possible to vary the sensing range of the pressure sensor. The desired sensing range was set to 3 N, and the maximum compression of the top face to 1.1 mm.

B. Electronic module

The electronic module is composed of a variable number of slave boards (from a minimum of one to a maximum of six) and a master board.

Each sub-module has a dedicated electronic board, *i.e.* slave board, for the acquisition and conditioning of pressure signals coming from the transduction module. The board is based on the STM32F4 microcontroller unit. In order to reduce the number of signals that the microcontroller has to manage, the slave board implements an additional multiplexing level, passing from the 48 analog input signals, to 12 collective signals. The signals are digitalized by three A/D converters, configured to work with 21-MHz clock and 12-bit resolution. Collected data are stored into 16-bit registers, and then sent to the master board using a SPI connection. In the design phase of the mat, several technical aspects have been taken into account, such as multiplexer delay, possible A/D configurations and communication strategies. A trade-off has been obtained yielding a maximum sampling frequency, on all 768 sensors, for each sub-module, of 20 Hz.

The master board, which is also based on a STM32F4 microcontroller, implements a finite state-machine which allows to: (i) trigger the acquisition phase of all connected slaves; (ii) receive data from slave boards; and (iii) send data to a remote computer through a USB virtual com port.

III. Experimental characterization

We tested the capability of the sensorized mat to discriminate about objects with rectangular (50x100 mm^2) and quadratic sections (50x50 mm^2), and with three different weights, namely 1, 2 and 3 kg.

As we did in [8], we used mat composed of two sub-modules, two slave boards and a master board. A custom Labview interface running on a remote computer, was used to acquire data from the master board at a sampling frequency of 10 Hz. All the six test objects were placed, at the same time, onto the overall sensorized surface of the mat, and a steady-state 32x48 pressure map was recorded, by averaging the output voltage of each sensor over 0.5 seconds. In order to emphasize pressure spots, collected pressure maps were filtered: (i) the output voltage of the single sensitive element was set to zero if its value was lower than the noise threshold of 0.0071 V; (ii) the pressure map was then filtered by means of a median filter (Matlab®, medfilt2 function), to remove outliers and to smooth the pressure spots. Output voltages were then converted into forces (Figure 2).

From the visual analysis of the pressure map it raises that different pressure spots are evident on the mat surface. Three smaller spots are localized in the upper quadrants of the map, which correspond to the square geometries. We can also discriminate from the lighter objects, on the left side, to the heavier ones, on the right side. It is worth noting that the sensitivity of the sensor is not sufficient for an accurate discrimination of the lighter objects (weight lower than 2 kg).

A more accurate analysis of the pressure of each spot, showed an underestimation of the object's weight, except for the rectangular geometries with the weight of 1 kg, that is overestimated (Table 1). This behaviour can be explained by the error introduced by the adopted force-to-output voltage numerical model, which can either overestimate or underestimate the actual force applied on each sensitive element (as extensively described in [8]).

TABLE I
Weight and pressure of each object

Object	*Weight [kg]*	*Pressure [kPa]*
Quadratic objects	1	4÷6
	2	13÷17
	3	15÷25
Rectangular objects	1	5÷15
	2	9÷11
	3	9÷18

IV. Conclusion

The analysis of recorded pressure map shows that it is possible to recognize consistent spots corresponding to objects with different shapes and different weight. Despite the limited accuracy in the estimation of the weight of the objects, this is not a limiting factor for using this device to collect pressure maps, which bring exhaustive information about the spatial localization of pressure spots.

Future works will aim at increasing the sensitivity of the transduction units for low pressure, modifying the silicone cover and implementing a new force-to-output voltage numerical model, and testing the sensorized mat in clinical trials. Furthermore, a deeper investigation of the dynamic response of the sensor will be performed.

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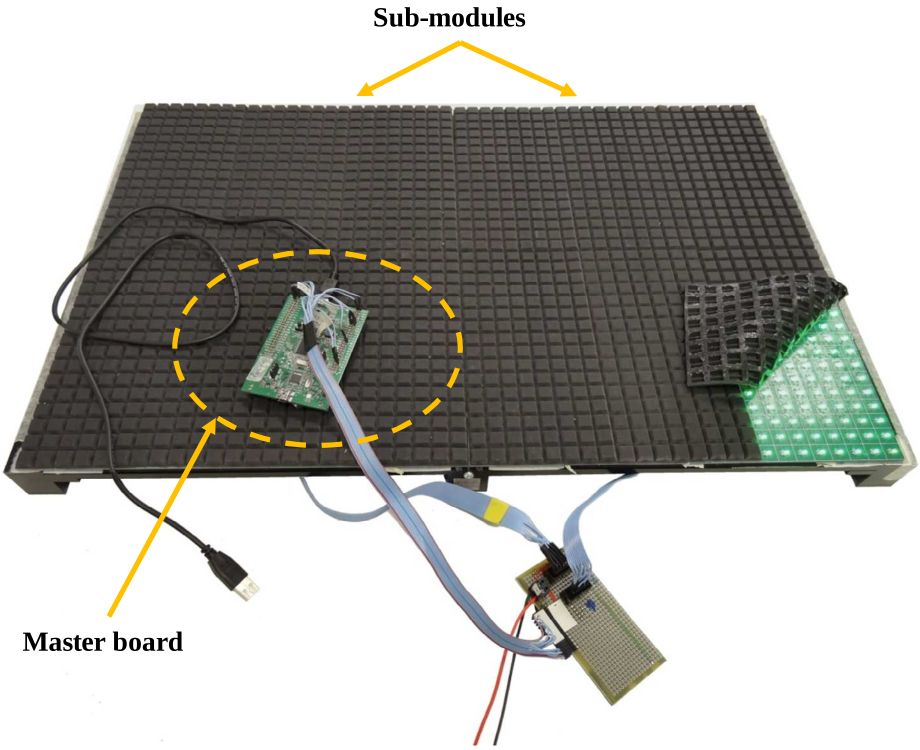

Fig. 1. Sensorized map housed onto a rigid plastic frame. The device is composed of two sub-modules, two slave boards housed under the transduction modules, and a master board.

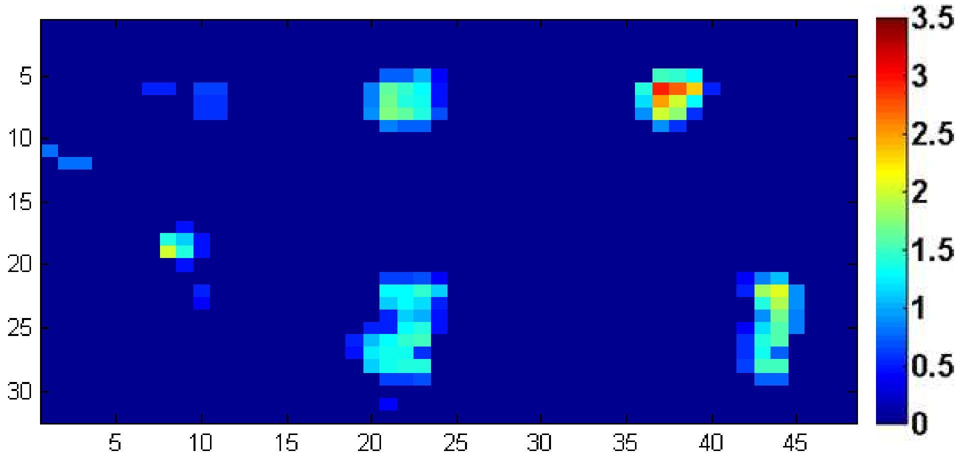

Fig. 2. Pressure map. Upper side: geometries with square shape of, from left to right, a weight of 1 kg, 2 kg, and 3 kg; lower side: geometries with rectangular shape of, from left to right, a weight of 1 kg, 2 kg, and 3 kg. Color scale is in [N].