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Wearable Multi-Modal Sensor Array with Wireless Communication for Monitoring Medical Bandage Condition

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Summary:
A portable bandage monitoring device was developed consisting a flexible, multimodal sensor system integrated with the preliminary signal readout and processing electronics. The sensing part of the device is designed to be bendable and compatible with bandage environment. The rigid part of the electronics is dedicated to collect the sensor's data streams and to communicate with the driving PC or mobile device via Bluetooth protocol. Via this wireless communication, the computer can receive the data flow and evaluate to visualise the bandage condition. Calibration and preliminary functional validation was elaborated to verify its capability of the device for measuring temperature, moisture and pressure distribution under the bandage. Android based application was also developed for processing and visualizing the characteristic parameters of the bandage to provide comprehensive information or warning signal for the doctors during remote supervision and home care.

Keywords: wearable, multi-modal, sensor array, smart bandage, wireless, wound monitoring

Introduction

In clinical practice, the proper use of bandages and care of wounds has primary importance in case of treatment postoperative and ulcerative injuries or varicose veins. Accordingly, to get continuous or regular information on the bandage condition without removal or remotely could decrease the required intervention time and improve the success of cure. [1] In case of home-care of the patient the remote monitoring of significant physico-chemical parameters of the bandage or wound could be crucial. The "intelligent bond" is to facilitate the work of the physician and the cure of the patient by monitoring the process of healing.

On that score "smart" bandage monitoring sensor array was developed with low power consumption readout, signal processing and communication electronics to facilitate continuous supervision by mobile device. [2] The intelligent system enable to provide continuous multimodal information of bandage parameters as temperature, moisture and local tightness / pressure of the bandage. In case of an emergency it could immediately warn the user and the physician about the need for checking or replacing the bandage.

Materials and Methods

The integrated wireless monitoring system consists of a rigid and a flexible part as demonstrated in Fig. 1. The flexible PCB contains all the sensors in an adequate geometry for measuring the local compression (five FSR pressure sensors), temperature and moisture (SI7021 sensor hub) under the bandage. The applied multiple pressure sensors are able to measure the inhomogeneous, perimeter dependent pressure distribution. It has a biocompatible coverage ensuring moisture intake.

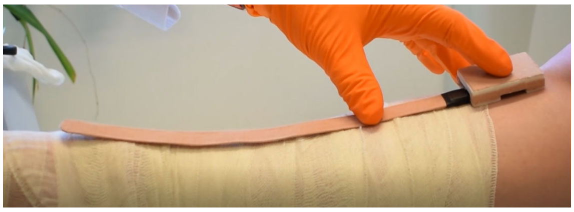

Fig. 1. Bandage monitoring system with the flexible sensing and the rigid signal processing / communication part.

The rigid part (Fig. 2) contains an EFM32 with an ARM Cortex M0+ core and 32 kB flash memory with the advantage of energy efficient operation with several energy modes. Analogue modules include ADCs, DACs, operational amplifiers, and analogue comparators. It also contains an RF module – RFD22301 Arduino based Bluetooth low energy MCU for wireless communication. This device can operate also in low energy modes (BLE – Bluetooth Low Energy). To connect flexible and rigid part USB C connector was applied.

Data processing and visualisation software was also developed. For testing the proper functionality of the sensor system, as well as their influence on the operation behaviour various tests and calibrations were elaborated by using different bandages applied in medical practice.

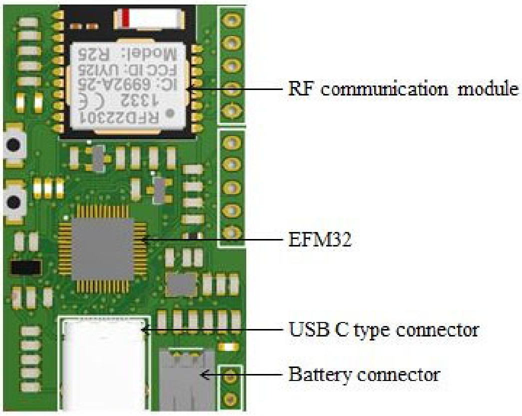

Fig. 2. Schematic architecture of the signal processing / communication electronics.

Results

To verify the applicability and reliability of the sensor system the physical parameters of different compression bandages / stockings were monitored during wearing in normal conditions for one hour. Two types of medical aids were tested as summarized in Table 1.

Table 1. Applied compression stockings

Type	***Compression range***	***Sizes***
Elastostar	*II.* *23-32 Hgmm*	*S-M-L*
Pharmatextil Elastobar	*III.* *34-46 Hgmm*	*S-M-L*

The local pressure values were collected, filtered and analysed. The compression of the stockings decreased from the ankle (F4 position) to the knee (F0 position) as expected and demonstrated in Fig. 3 and 4 in case different types of aids. The difference between the II. and III. types of stocking is also verified clearly, although the measured pressures were experienced higher than defined. Therefore, the adequate setting, wearing conditions and position of the patient were considered. As Fig. 5 demonstrates the pressure values are almost invariable near the knees, however increased notably near the ankle comparing standing and sitting positions.

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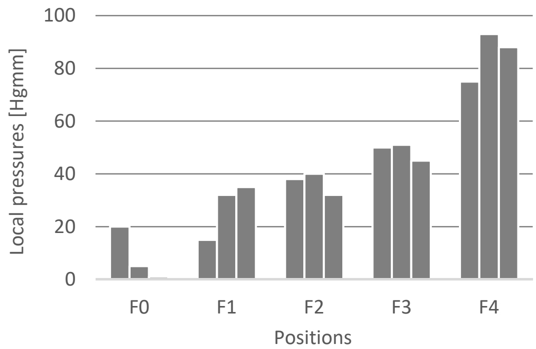

Fig. 3. Pressure distribution along the lower leg from the knee (F0) to the ankle (F4) wearing Type II compression stocking.

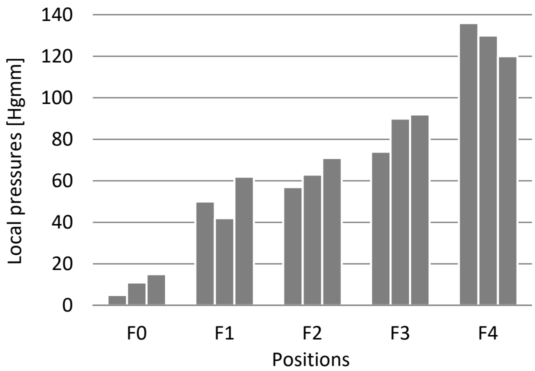

Fig. 4. Pressure distribution along the lower leg from the knee (F0) to the ankle (F4) wearing Type III compression stocking.

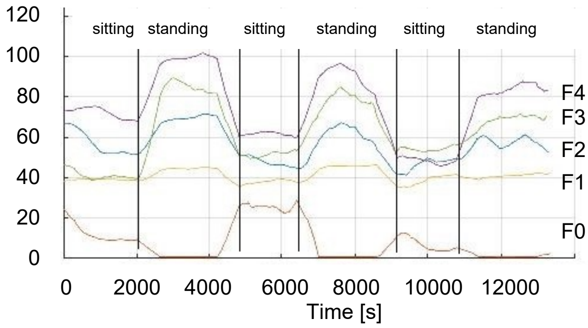

Fig. 5. Pressure values measured in different positions (pressure 1: ankle – pressure 5: knee) along the lower leg in case standing and sitting patient.

References

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[2] Tim R. Dargaville, Brooke L. Farrugia, James A. Broadbent, Stephanie Pace, Zee Upton, Nicolas H. Voelcker, Sensors and imaging for wound healing: A review, Biosensors and Bioelectronics 41 (2013) 30–42