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Textile polymer optical fiber sensors for long-term measurements

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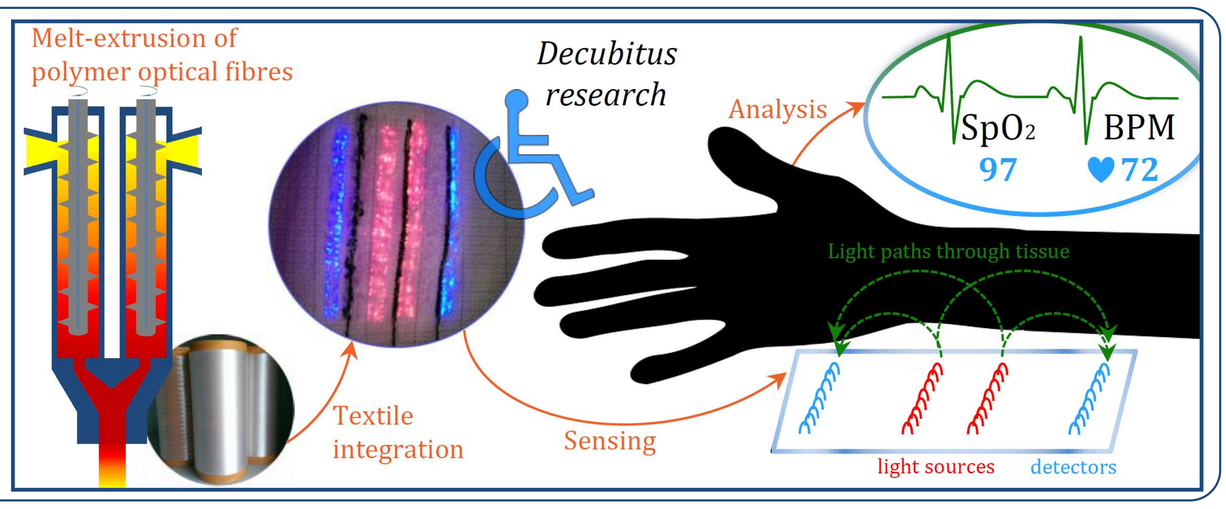
Introduction

Decubitus ulcers are still widely spread among paraplegics due to incomplete understanding of the mechanisms of tissue breakdown. However, the skin condition of each individual patient is an important indicator in pressure ulcer prevention. Among others, threshold values for perfusion linked to load on tissue over time are unknown. However, to detect early changes in skin as in perfusion and oxygen saturation to prevent injury with therapeutic intervention could increase the patients' quality of life drastically.

To help develop precaution protocols, flexible, textile measurement set-ups need to be developed for long-term measurements. Here, we present polymer optical fiber fabrics (POFFs) for sensing the heartbeat.



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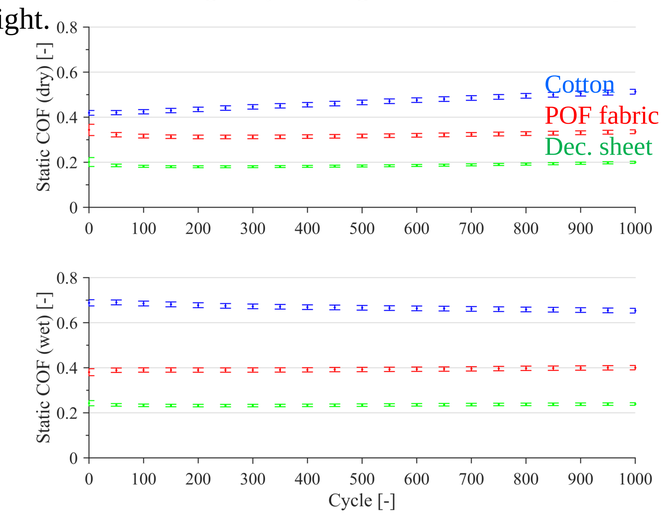
Dermatologic considerations

Most existing options with flexibility create additional pressure points that chafe the skin. They hence increase ulcer development risk. Here, we present the development of a sensor that uses newly-optimized polymer optical fibers for sensing and detecting the heart beat.

The detection mechanism is based on the attenuation of light by hemoglobin and the subsequent pulsatile amplitude changes in detected light.

Friction

The static coefficient of friction (COF) is evaluated in dry and sweaty conditions versus a skin model (Lorica). A load (8.5 N) is used corresponding to the load experienced from the ischial tuberosity. 1000 cycles are evaluated. The sensor textile shows a lower COF than conventionally-used bedsheets with the substrate fabric for comparison.



Washing

The sensor was washed with a hospital-grade detergent (40 °C, 45 min). The out-coupling light intensity was measured showing an increase in intensity due to removal of dust.

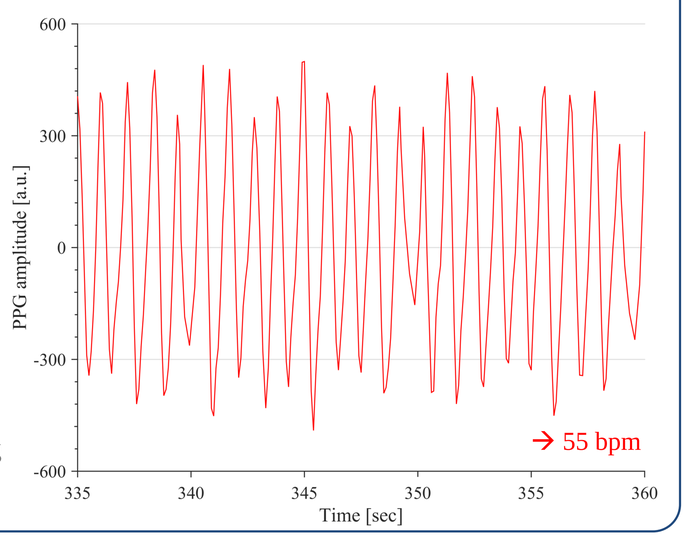
The stability of the sensor shown here makes the development economically and environmentally friendly.

The superscripts "a, b, c" identify samples which do not show significant differences ($p < 0.05$).

Sensor testing

The produced sensor was tested with dedicated electronics based on the photoplethysmography acquisition chain. A commercial infrared LED (λ=870) and a phototransistor were used for data acquisition.

Recording in reflection mode also enables higher freedom in sensor location. The heartbeat was recorded on a finger while resting on a table. To avoid motion related artifacts, the subject was sitting with the arm resting on the table.



PPG amplitude with a Savitzky-Golay smoothing filter (polynomial order = 3, frame size = 7)

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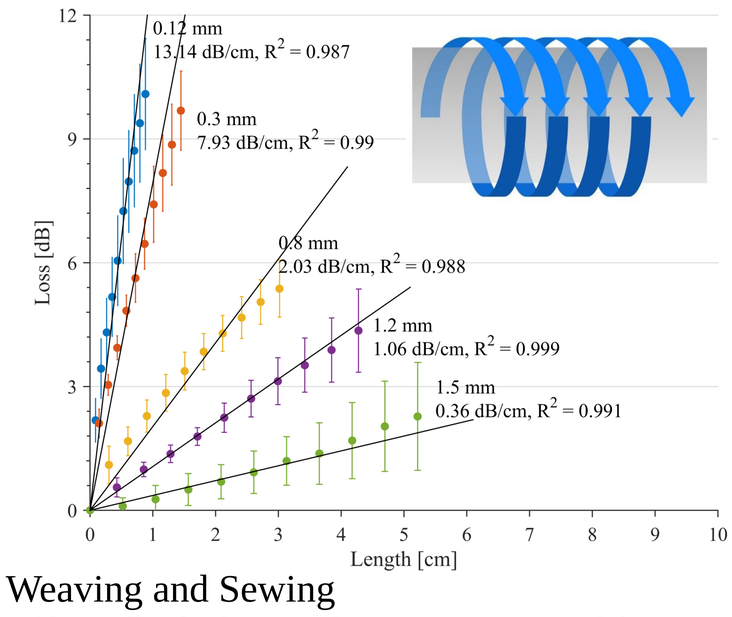
Optimization of optical fibres' performance

To increase the efficiency of the sensors even further, the out-coupling process was investigated in detail. For this, the losses arising from different bend curvature radii are evaluated. Additionally, the connection of polymer optical fibres to the LEDs is optimized.



Bend out-coupling

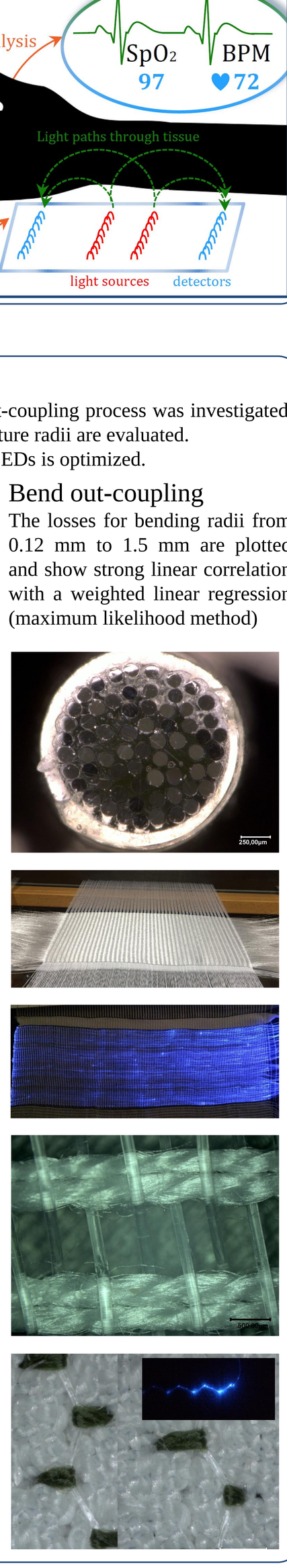
The losses for bending radii from 0.12 mm to 1.5 mm are plotted and show strong linear correlation with a weighted linear regression (maximum likelihood method)

Weaving and Sewing

Additionally, for larger radii, weaving was used for a quick production. Within these experiments, large areas of lighting fabric were produced. They were additionally analysed in terms of out-coupling homogeneity in respect to light source distance. Sewing provided another simple production technique and defined fixation angles by parameter adjustment (as can be seen in the image (bottom right).

Post-processing of polymer optical fibres

To improve the optical properties further, we are currently working on post-processing of the fibres by means of hot-drawing. There, typical stress curves for hot-drawing were observed.



Conclusion and Outlook

It is shown that the developed polymer optical fibres can be embroidered with a commercial embroidery machine. The sensor can then be run on a LED/phototransistor setup compared to the previously-used laser configuration. We have shown that the sensor withstands hospital-type laundry cycles. The POF textile shows a lower coefficient of friction in both wet and dry conditions than standard cotton bedsheets over 1000 cycles.

Regarding the optimization of the optical fibres, both small and large radii were investigated to accurately define the amount of out-coupled light. Larger radii were explored by textile production means. Sewing and weaving both show quick production and pleasant tactile feel. Currently, further post-processing of the optical fibres with both hot- and cold-drawing at slow speeds is evaluated for improved attenuation behaviour.

Acknowledgements

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