Transactions on Additive Manufacturing Meets Medicine
Trans. AMMM, 2026, Vol. 8, No 1, Suppl. 1, Article ID 2740, 1 Page

Abstract

GlucoSole: 3D-printed plantar pressure sensing insole for combined resistive and capacitive sensing

F. Seidensticker[1,2,3*], P. Stagge[2], M. T. Gabrecht[1,2], R. Schlonsak[1,2], and D. J. C. Matthies[1,2]

[1] *Technical University of Applied Sciences Lübeck, Lübeck, Germany*
[2] *Fraunhofer Research Institution for Individualized Medical Technology and Engineering IMTE, Lübeck, Germany*
[3] *Institute of Medical Engineering, University of Lübeck, Lübeck, Germany*
[*] *Corresponding author, email: franziska.seidensticker@th-luebeck.de*

Diabetic foot syndrome affects approximately one in three to four diabetes patients and requires amputations above the ankle in almost 50% of cases. Microcirculation disorders cause reduced sensation, delayed wound healing, and altered gait patterns with an increased risk of falling. Hence, sensor-supported shoe insoles for monitoring of plantar pressure distribution in elderly diabetes patients are beneficial for early detection of foot ulcer. This research focuses on the additive manufacturing of innovative sensor technologies for non-invasive, mobile detection of pressure changes and gait anomalies.

Following a comprehensive survey- and technology-analysis, a hybrid sensor approach was chosen that combines a resistive and capacitive pressure measurement. Force Sensitive Resistors (FSR) offer robustness at high pressures, while Capacitive Sensing (CapSense) enables precise measurements of low pressures that comes with greater distances between the sensor and the foot. In this research, the electrodes, which are the main part of the sensors are manufactured entirely additively using the Nano Dimension DragonFly IV circuit board printer in an inkjet process. Conductive AgCite silver nanoparticle inks and dielectric UV-curing acrylate inks are used at a resolution of 18 µm (x/y) and 10 µm (z). We add Velostat material, a carbon-impregnated polyethylene composite, that is positioned between the printed electrodes and changes its electrical conductivity under pressure, serves as the piezoresistive material.

In an iterative process, different generations of prototypes were developed. The first prototype served to prove the functionality of both measurement principles. The second prototype was characterized in terms of mechanical properties with bending tests. All sensor sizes, which were considered, are sufficiently flexible for an insole integration. Signal-to-noise ratio measurements were additionally performed with reliable measurements possible at loads of up to 900 N (corresponding to >90 kg body weight) and values above 30dB for the larger sensors, which were then used for further development. The third prototype integrates six sensors driven by an ESP32-S3 microcontroller, which also enables wireless data transmission via Bluetooth Low Energy (BLE) to test the infrastructure of the whole system. The fourth prototype is currently under development, which features a 2-dof Inertial Measurement Unit (IMU) for three-dimensional acceleration and rotation measurement. To ensure that all components fit into an insole, a customized manufactured circuit board is designed. Finally, an app for data acquisition and visualization is developed, to allow for technical validation under real-world conditions. Since we now have the infrastructure, we will be enabled for an AI-supported gait analysis for the early detection of pathological changes, hypoglycemia and fall prevention in diabetic patients in future.

AUTHOR'S STATEMENT
Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Research funding: This research is funded by the Federal Ministry of Research, Technology and Space of Germany (03DPC0711A) under the DATIpilot initiative: GRANNI (Gesundes und resilientes Altern durch nachhaltige Medizintechnik aus der Norddeutschen Hanse Innovation Community).

DOI: 10.18416/AMMM.2026.26062740