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A 2-D and 3-D Embroidered Textrode Testing Framework Adhering to ISO Standards

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Abstract : Smart fabric garments enable various monitoring applications across sectors such as healthcare, sports and fitness, and the military. Healthcare smart garments monitoring EEG, EMG, and ECG rely on the use of electrodes (dry or wet). However, such electrodes, when used for long-term monitoring, can cause discomfort and skin irritation for the wearer because of their inflexible structure and weight. Ongoing research has been investigating textile-based electrodes (textrodes) in order to provide more comfortable and usable fabric-based electrodes capable of providing intuitive biopotential monitoring. Progress has been made in this space, but they still face a critical design challenge in maintaining consistent skin contact, which directly impacts signal quality. Furthermore, there is a lack of an ISO-based testing framework to validate the electrode design and assess its ability to achieve enhanced performance, strength, usability, and durability. This study proposes the development and evaluation of an ISO-compliant testing framework for standard 2D and advanced 3D embroidered textrodes designs that have a unique structure in order to establish enhanced skin contact for the wearer. This testing framework leverages ISO standards: ISO 13934-1:2013 for tensile and zone-wise strength tests; ISO 13937-2 for tear tests; and ISO 6330 for washing, validating the textrode's performance, a necessity for wearables health parameter monitoring applications. Five textrodes (C1-C5) were designed using EPC win digitization software. Varying patterns such as running stitches, lock stitches, back-to-back stitches, and moss stitches were used to create various embroidered tetrodes samples using Madeira HC12 conductive thread with a resistivity of 100 ohm/m. The textrode designs were then fabricated using a ZSK technical embroidery machine. A comparative analysis was conducted based on a series of laboratory tests adhering to ISO compliance requirements. Tests focusing on the application of strain were applied to the textrodes, and these included: (1) analysis of the electrode's overall surface area strength; (2) assessment of the robustness of the textrodes boundaries; and (3) the assignment of fault test zones to each textrode, where vertical and horizontal slits of 3mm were applied to evaluate the performance of textrodes and its durability. Specific ISO-compliant tests linked to washing were conducted multiple times on each textrode sample to assess both mechanical and chemical damage. Additionally, abrasion and pilling tests were performed to evaluate mechanical damage on the surface of the textrodes and to compare it with the washing test. Finally, the textrodes were assessed based on morphological and surface resistance changes. Results demonstrate that textrode C4, featuring a 3-D layered structure consisting of foam, fabric, and conductive thread layers, significantly enhances skin-electrode contact for biopotential recording. The inclusion of a 3D foam layer was particularly effective in maintaining the shape of the electrode during strain tests, making it the top-performing textrode sample. Therefore, the layered 3D design structure of textrode C4 ranks highest when tested for durability, reusability, and washability. The ISO testing framework established in this study will support future research, validating the durability and reliability of textrodes for a wide range of applications.

Keywords : smart fabric, textrodes, testing framework, ISO compliant
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