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Anomaly Detection in Knitting Machines for Medical Compression Socks Using Performance Indicators based on Quadrant Analysis, and PCA-Based K-means Clustering

Chronic Venous Insufficiency (CVI) affecting the lower extremities is common among adults. Compression textile products, such as compression socks, play a crucial role in the treatment and prevention of CVI and other lower-limb disorders [1], [2]. By applying controlled external pressure, these products support venous return and alleviate symptoms such as pain, edema, and venous hypertension [2], [3], [4]. Since the clinical effectiveness of compression therapy depends on an appropriate pressure profile and patient adherence, manufacturing defects that affect fit, comfort, or pressure distribution may compromise therapeutic performance and user comfort [5], [6].

This study originates from a practical industrial issue: the occurrence of appearance-related and dimensional defects in medical socks detected during quality inspections. Identifying the causes of these defects is essential to improve product quality and optimize quality control procedures.

The analysis is based on annual production data from circular knitting machines used to manufacture compression socks, including total production, number of defects, and number of machine events. From these data, three performance indicators were derived: defect rate, event rate, and defect rate per event. Together, these indicators describe quality outcomes, operational stability, and the severity of machine-related events. As a first level of analysis, an engineering-oriented quadrant analysis was developed using event rate and defect rate per event. Quadrant-based approaches are widely used in engineering and management as intuitive tools for performance assessment, prioritization, and anomaly detection, particularly when combining frequency- and impact-related metrics [7], [8], [9]. Reference thresholds based on mean values enabled the classification of machines into four categories: critical, high risk, inefficient, and optimal. This representation provides a transparent tool for anomaly detection and constitutes the first set of results of the study.

To improve and complete the quadrant-based analysis, Principal Component Analysis (PCA) was applied to the performance indicators. PCA is widely used in engineering and industrial contexts to capture latent multivariate structures and support visual classification of complex systems [10]. Previous studies have shown its effectiveness in identifying machine clusters and validating grouping results across datasets [11], [12]. In this study, the first two principal components explained more than 96% of the total variance, representing overall operational burden and event severity. The PCA projection revealed coherent machine groupings as well as borderline and extreme behaviors not evident in univariate analyses.

Subsequently, K-means clustering was applied to the PCA scores to obtain a data-driven classification of machine performance. The resulting clusters consistently isolated machines with anomalous behavior, such as high event severity or frequency, while also identifying machines with stable and near-optimal performance. The proposed methodology represents an essential step toward improving quality control in compression sock manufacturing. By providing a reliable classification of machine behavior, this work lays the groundwork for future studies on defect-specific correlations, reprocessing monitoring, and predictive quality control strategies. More broadly, it demonstrates how performance indicators and multivariate analysis can support continuous improvement in the production of medically relevant textile products. Finally, feedback from industrial experts supports the interpretation of the results and their practical significance.

[1] Y. Shi, R. Liu, J. Lv and C. Ye, "Biomedical therapeutic compression textiles: Physical-mechanical property analysis to precise pressure management," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 151, 2024.

[2] E. Akçagün, F. Siddique and A. Yilmaz, "Development of seamed compression socks and comparison with class i socks using existing mathematical models," *Journal of The Faculty of Engineering*, vol. 28, no. 3, 2023.

[3] C. S. Lim and A. H. Davies, "Graduated compression stockings," *Canadian Medical Association Journal*,

vol. 186, no. 10, pp. 391-398, 2014.

[4] B. Sarı and N. Oğlakcioğlu, "Analysis of the parameters affecting pressure characteristics of medical stockings," *Journal of Industrial Textiles*, vol. 47, no. 6, p. 1083–1096, 2018.

[5] B. Yang, Y. Xiong, S. Liu, F. Wang and X. Tao, "Assessment of spatial and temporal pressure distribution of compression stockings during 8-hour wear by using a smart bionic morphing leg mannequin," *Measurement*, vol. 262, p. 120057, 2026.

[6] J.-M. Gong, J.-S. Du, D.-M. Han, X.-Y. Wang and S.-L. Qi, "Reasons for patient non-compliance with compression stockings as a treatment for varicose veins in the lower limbs: A qualitative study," *PLoS One, Public Library of Science*, vol. 15, no. 4, pp. 1-11, April 2020.

[7] H. Pires Ferreira and P. Odete Fernandes, "Importance-performance Analysis Applied to a Laboratory Supplies and Equipment Company," *Procedia Computer Science*, vol. 64, pp. 824-831, 2015.

[8] J. Sarker, J. Hong and C. Im, "Innovation Strategies for Textile Companies in Bangladesh: Development Using Quadrant Analysis Based on a Productivity Index," *Sustainability*, vol. 14, no. 24, pp. 1-15, December 2022.

[9] A. Shahin and T. Hamidreza, "Investigating the supplier-producer relationship quality: a gap-quadrant analysis approach," *Research in Production and Operations Management*, vol. 14, no. 4, pp. 31-48, 2024.

[10] F. Alves de Almeida, G. Ferreira, P. Balestrassi, G. Belinato, R. P.A.R and M. Achilles, "Principal Component Analysis: An Overview and Applications in Multivariate Engineering Problems," in *Uncertainty Modeling: Fundamental Concepts and Models*, Brasília, DF, Brazil, University of Brasília, 2022, pp. 172-194.

[11] M. Chattopadhyay, S. Mazumdar, P. K. Dan and P. S. Chakraborty, "Application of principal component analysis in machine-part cell formation," *Management Science Letters*, vol. 2, no. 4, pp. 1175-1188, 2012.

[12] W. Hachicha, F. Masmoudi and M. A. Haddar, "Principal component analysis model for machine-part cell formation problem in group technology," *Applications*, 2006.

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