

Smart Textile Using Embroidered Cu-Zn-Coated Aramid Threads for ECG Monitoring

Maham Sajjad¹, Muhammad Uzair Shokat², Xinwang Cao^{1,*}

¹ Department of Textile Engineering, Wuhan Textile University, Wuhan, China

² Department of project management, university of law, Manchester, United Kingdom

Email: ¹ maihamasajjad@gmail.com, ² uzairmalik197@gmail.com, ³ aswang1984@163.com

*Corresponding Author (Xinwang Cao E-mail: aswang1984@163.com)

Abstract— This study presents the design and evaluation of a smart textile ECG monitoring garment developed for continuous, comfortable, and reusable cardiac health tracking. The system incorporates Cu-Zn-coated aramid conductive threads embroidered onto a polyester-cotton knitted fabric to form dry textile electrodes, which are connected to a wireless ECG sensing unit based on the AD8232 analog front end and an ESP32 microcontroller for real-time signal transmission. A lightweight polyethylene sheet was integrated beneath the electrodes and circuitry to provide water and sweat resistance without significantly compromising comfort. Characterization tests showed low electrode resistance (10–20 Ω), washability up to 10 cycles, and good mechanical durability. The device captured clear PQRST waveforms at a 250 Hz sampling rate with a signal-to-noise ratio of 15–25 dB, achieving 90–95% signal quality compared to gel electrodes under resting conditions. Air permeability decreased slightly with embroidery and more significantly in polyethylene-backed regions, though the garment remained wearable and breathable. User testing confirmed accurate heart rate detection and high comfort, with ECG signals stabilizing within 30 seconds of wear. These findings demonstrate that the smart textile ECG garment is a viable, comfortable, and reusable alternative to conventional systems, suitable for long-term and home-based cardiac monitoring applications.

Keywords— Smart textiles, textile electrodes, embroidered sensors, wireless cardiac monitoring, washable electronics, real-time health monitoring

I. INTRODUCTION

Cardiovascular diseases remain a leading cause of mortality worldwide, underscoring the critical need for improved cardiac monitoring and early interventions [1-3]. ECG is essential for detecting cardiac abnormalities, but brief clinical recordings may miss intermittent arrhythmias triggered by specific activities [4, 5]. Continuous long-term ECG monitoring addresses this gap by capturing heart activity over extended periods, enabling early detection of conditions like atrial fibrillation or silent ischemia [6]. Timely identification allows for prompt intervention, potentially improving outcomes and preventing severe cardiovascular events [7]. In the past years, Holter monitors have allowed 24–72 hour ECG recording, but have limitations for long-term use. Their adhesive gel electrodes and multiple wires can cause

discomfort, restrict movement, and lead to skin irritation as the gel dries, degrading signal quality [8, 9]. 72-hour drawbacks reduce user compliance and make traditional Holter systems impractical for continuous, everyday heart monitoring over extended periods despite their clinical utility [10]. Wearable health technology offers a practical solution to the limitations of traditional ECG systems by enabling continuous, at-home heart monitoring through smart textiles [11]. These garments use dry, textile-based electrodes made from conductive materials that conform to the body, eliminating the need for adhesives and reducing skin irritation. Embroidered electrodes are particularly effective, providing stable contact, low impedance, and high-quality ECG signals in a form that is both comfortable and discreet [12].

Recent innovations have demonstrated the feasibility and benefits of embroidered-textile ECG electrodes. Ankhilli et al. developed embroidered electrodes using silver-plated polyamide threads and showed that their ECG performance remained reliable even after 50 wash cycles, illustrating the durability of this approach [6]. In a comparative evaluation of different textile electrode types, a handmade embroidered electrode achieved the highest signal accuracy among several designs tested, with superior performance attributed to the optimized contact provided by the embroidery pattern and conductive yarn [13]. Beyond silver-coated fibers, researchers have explored carbon-based and polymer-based alternatives. Graphene- or carbon-nanotube-infused fabrics have been produced that offer good conductivity and flexibility while being washable for long-term use [14]. Likewise, conductive polymer inks, such as PEDOT: PSS, have been screen-printed onto fabric to form dry electrodes capable of reliable ECG acquisition without causing skin irritation. Each of these material innovations is aimed at achieving low skin-electrode impedance and high signal fidelity, while remaining soft, lightweight, flexible, and unobtrusive on the body, key qualities for successful long-term wearable ECG monitoring [15]. Arquilla et al. found that sewn textile electrodes using conductive fabrics could capture clinical-quality ECG signals while offering improved skin comfort [16]. Similarly, printed dry electrodes on fabric substrates have emerged as scalable and washable



Received: 18-8-2026

Revised: 20-9-2026

Published: 31-12-2026

alternatives for signal capture without adhesives or gels [17]. Avvaru et al. integrated Ag-NyW electrodes into smart jackets, demonstrating that flexible textile-based solutions can deliver accurate ECG readings even during motion, thanks to strategic placement and material conformity [18]. The importance of electrode location was further emphasized by showing that proper anatomical alignment is critical to minimizing motion artifacts and maintaining signal integrity [19]. Likewise, a study demonstrated that smart garments using conductive yarns could deliver long-term ECG monitoring in home environments, especially beneficial for the elderly and chronically ill population [20, 21]. Similarly, the study emphasized that selecting skin-compatible, flexible materials is essential not only for high signal fidelity but also for wearer comfort and long-term compliance [22 - 25]. Despite these advancements, many smart garments still appear overtly medical or lack aesthetic appeal, which can cause emotional discomfort or stigma among users [26, 27]. Moreover, motion artifacts during dynamic activity, integration of rigid electronics, and insufficient protection of components from water and air exposure limit their practical usability [28, 29].

II. METHODOLOGY

To address real-world limitations of ECG garments, I developed a smart wearable using Cu-Zn-coated aramid threads embroidered at key chest points for accurate signal capture. A polyethylene sheet was added for protection, and the material was tested using Hydrostatic Head and Air Permeability methods to confirm its water resistance and breathability. Conductivity tests validated the threads' electrical performance, and a full-system test confirmed reliable ECG signal acquisition and wireless transmission, making the garment durable, comfortable, and functional for daily use [30, 31].

A. Materials

Cu-Zn-coated aramid conductive thread (TA-NT7a-0.7 Gy-000 -N0,36 $\pm$ 0.35 MF) resistance of 1 Ω /m, sourced from China. The shirt was made from a blend of polyester/cotton knitted fabric, procured from Interloop Pvt Ltd., Pakistan. Wearable ECG module built around the AD8232 Heart Monitor analog front end, powered by a 450 mAh lithium-polymer (Li-Po) battery. The board includes connection terminals for power (3.3 V), ground, output, and shutdown control, and is capable of transmitting ECG data via Bluetooth or Wi-Fi when paired with a microcontroller (e.g., Arduino or ESP32). A lightweight polyethylene sheet, procured from the local market, was used as a water-resistant barrier to protect the ECG electronics.

B. Fabrication of smart textile garments

To begin the fabrication of the smart textile ECG garment, a blend of polyester-cotton knitted fabric was used, with a custom electrode pattern designed and embroidered onto the chest region of the garment, as shown in figure 1. Using Cu-Zn-coated aramid conductive thread, and for aesthetic and structural reinforcement, non-conductive polyester embroidery thread was also used in the design to outline and stabilize the electrode pattern. The embroidery was performed using a computerized embroidery machine to

ensure accuracy and consistency in the electrode placement. Three conductive thread electrodes, each with an average embroidered area of nearly 3 cm by 3 cm, were developed in the garment. Three of the electrodes were positioned: One placed on the right side of the chest, the second on the left side, and the third on the abdomen. The abdominal electrode was employed as the reference electrode; both chest electrodes were used as the main sensing electrodes. In order to maintain skin contact with the conductive embroidery, the garment pattern was designed with a fitted construction.

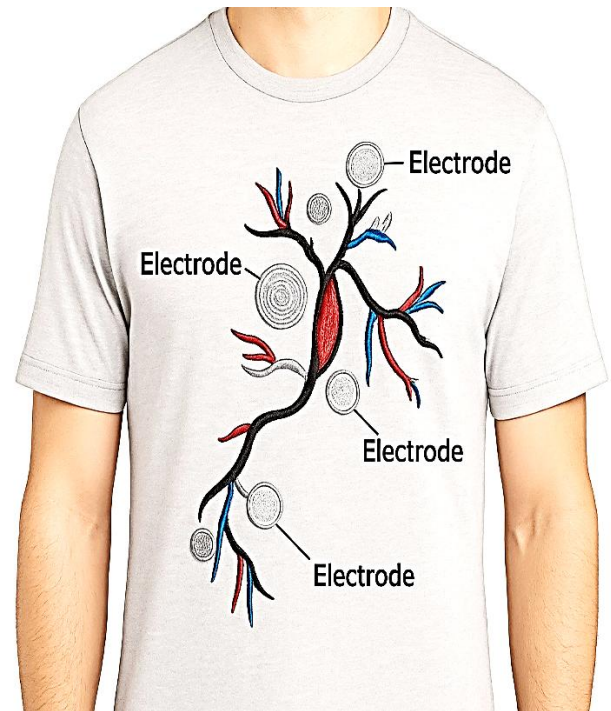


Figure 1: Embroidered electrodes smart textile garment

C. Integration of ECG sensing electronics

Following embroidery, the smart garment was integrated with an ECG sensing device. The embroidered electrodes were linked to the ECG module via conductive snap buttons or extension leads. The compact electronics unit was securely mounted on the inner back panel of the shirt. Once powered on, the system captured ECG signals and transmitted them wirelessly to a smartphone or PC, allowing real-time visualization and monitoring of the user's heart activity. To enhance wearer comfort and ensure the protection of embedded electronics, a lightweight polyethylene sheet, procured from the local market, was stitched onto the inner back layer of the garment. This sheet acts as a water- and sweat-resistant barrier, shielding sensitive components from moisture during daily use or washing. Despite its protective function, the polyethylene sheet maintains breathability, ensuring the garment remains comfortable for extended wear. Its integration significantly improves the durability, usability, and washability of the smart ECG garment.

D. Characterization of Smart Textile ECG

The characterization of the smart textile ECG garment involved a series of electrical, functional, and material performance tests. Initially, the embroidered electrodes made from Cu-Zn-coated aramid threads were evaluated using a

digital multimeter to measure electrical resistance, confirming their conductivity and suitability for biosignal transmission. To validate system functionality, the complete garment, integrated with the AD8232 ECG module, Li-Po battery, and Bluetooth/Wi-Fi-enabled microcontroller, was tested for real-time ECG signal acquisition and wireless data transmission to a smartphone or PC. A spray test, based on AATCC 22/ISO 4920 standards, was conducted on the polyethylene layer to assess water resistance and ensure protection of embedded electronics from sweat and moisture. Air permeability testing (ASTM D737/ISO 9237) confirmed that the polyethylene sheet maintained adequate breathability for wearer comfort. The test performed was a comparative breathability assessment rather than a standardized laboratory-based air permeability test according to ASTM D737 or ISO 9237. This evaluation was conducted to determine the airflow passing through the garment before and after integration of embroidery a protective polyethylene layer. The second purpose was to test whether the garment would remain comfortable and breathable while being worn. This test helped to assess integration of conductive embroidery and ECG elements would affect the breathability of the garment. Wash durability was evaluated by subjecting the garment to repeated hand wash and air-dry cycles, followed by re-testing of electrode resistance and ECG functionality to confirm long-term usability. A short-term wear trial was also performed to assess comfort, electrode contact stability, and ease of use during basic movement. Additionally, electrode placement was verified against standard ECG lead positions to ensure accurate cardiac signal detection. These characterizations collectively demonstrated the electrical reliability, user comfort, and functional durability of the smart ECG garment under real-world conditions.

III. RESULTS AND FINDINGS

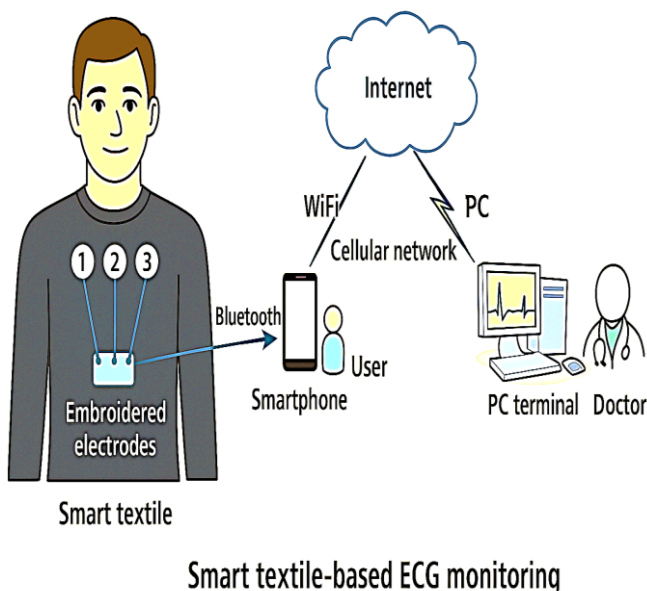


Figure 2: Smart Textile-Based ECG Monitoring Model

A. Textile Electrode Performance

The performance of the textile electrodes was evaluated through multiple metrics, including electrical resistance,

washability, skin comfort, and durability. The measured electrode resistance ranged from approximately 10 to 20 ohms for silver yarn patches under dry conditions, indicating sufficiently low resistance to enable reliable biopotential signal transmission for ECG monitoring. Washability tests demonstrated that the electrodes retained their structural integrity and electrical performance for up to 10 washing cycles using mild detergent, confirming their suitability for repeated use in daily wearable applications. In terms of skin comfort, the use of soft, flexible textile substrates and dry-contact materials eliminated the need for adhesive gels, resulting in high wearer comfort with no reported skin irritation, even during prolonged wear. Durability assessment showed only minor fraying after 20 or more wear cycles, suggesting that the embroidered structures maintained their mechanical and electrical performance over time with normal usage. Additionally, it was observed that embroidered electrodes with a 3 cm diameter provided more stable and consistent skin contact than smaller designs, likely due to increased surface area and improved coverage over the measurement site, which reduced signal fluctuation and contact inconsistency. These findings validate the embroidered textile electrode design as a viable, reusable, and user-friendly alternative to conventional gel electrodes in wearable ECG systems.

B. Signal Quality

The signal quality of the embroidered textile electrode system was assessed based on key electrocardiographic parameters. The system successfully captured distinct PQRST waveforms, demonstrating its effectiveness in detecting core components of the cardiac cycle under resting conditions. The measured signal-to-noise ratio (SNR) ranged between 15–25 dB, which falls within the acceptable range for wearable ECG devices and indicates sufficient signal clarity relative to background noise. Baseline wander, caused by factors such as respiration or subtle body shifts, was observed but remained within a range that could be corrected using standard digital high pass filtering techniques. Motion artifacts—transient distortions due to body movement—were present during physical activity but were significantly reduced by ensuring a snug garment fit, which helped maintain consistent electrode-skin contact. The system operated at a sampling rate of 250 Hz using the AD8232 analog front end, which is adequate for capturing the frequency components of the ECG waveform (typically <100 Hz) with sufficient temporal resolution for clinical and monitoring applications. These results confirm that the smart textile ECG system can produce clinically interpretable signals suitable for both stationary and light ambulatory use.

C. Water/Sweat Resistance

To enhance the environmental durability of the smart textile ECG system, a thin, flexible polyethylene sheet was integrated into the garment as a backing layer positioned directly behind the embroidered electrodes and embedded electronics. This layer was selected for its hydrophobic properties, which effectively repel moisture from external sources such as sweat and washing water. By physically isolating the conductive paths and electronic modules from potential fluid exposure, the polyethylene barrier helps to preserve signal integrity, prevent short circuits, and extend

the functional lifespan of the system. Its flexibility ensures that it conforms to body movement without compromising wearer comfort or garment fit. The inclusion of this layer is essential for maintaining performance stability in real-world, washable, and wearable ECG applications.

D. ECG Testing

The smart textile ECG system demonstrated reliable heart rate detection within the normal 60–80 bpm range under resting conditions, with signal clarity and stability as shown in figure 3. Minimal baseline noise was observed during seated use, and signals remained readable even after mild activity, despite slight motion artifacts. During active movement, while signal stability declined due to motion, heart rate detection remained functional. All test subjects produced usable ECG signals within 30 seconds of wear and rated the textile electrodes as more comfortable than gel pads, highlighting both the technical efficacy and superior user comfort of the embroidered smart garment. The developed smart textile system successfully acquired and showed ECG signals by the embroidered conductive-thread electrodes.”

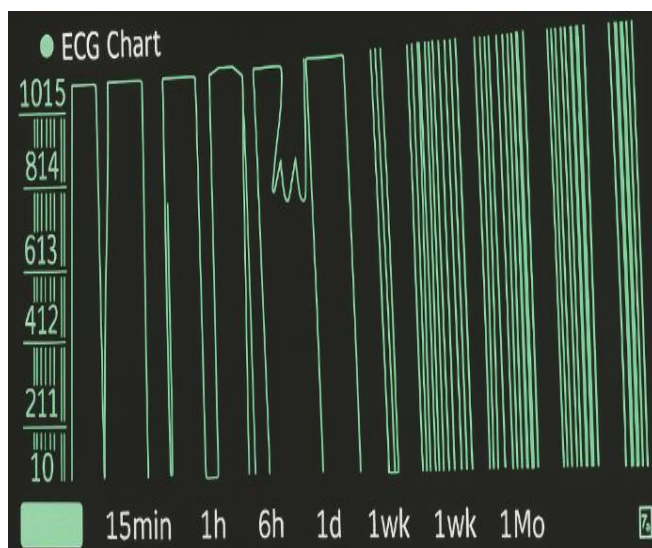


Figure 2: ECG results

E. Air Permeability

Air permeability testing was conducted to evaluate the breathability of different fabric configurations used in the smart textile ECG garment. The base polyester-cotton fabric demonstrated high air permeability at 400 L/m²/s under 100 Pa pressure, indicating excellent breathability and comfort in its unmodified form. After embroidery with conductive and polyester threads, the air permeability slightly decreased to 350 L/m²/s, likely due to the added thread density partially obstructing airflow. However, this reduction was minimal and still within an acceptable range for wearable comfort. In contrast, when the polyethylene sheet was added as a backing layer behind the embroidered electrodes and electronics, air permeability dropped significantly to 80 L/m²/s, reflecting the low porosity of the polyethylene film. The purpose of the polyethylene backing layer was to cover and shield the electronic components of the ECG from moisture. It was not originally designed to be the primary layer of skin contact. The garment was designed so that the

textile remained the primary contact layer. This study did not evaluate the impact of the polyethylene backing layer has no impact on long-term comfort. This result confirms that while the sheet provides effective moisture protection, it also restricts airflow beneath the covered area. Therefore, careful placement and limited coverage of the polyethylene layer are important to maintain overall garment breathability while ensuring water resistance.

IV. DISCUSSIONS

The results demonstrate that the developed embroidered smart textile can provide a practical balance between electrical performance, wearer comfort, and garment functionality. The relatively low electrode resistance and successful acquisition of recognizable PQRST waveforms indicate that Cu-Zn-coated aramid threads can be integrated into a textile structure for ECG signal acquisition. The use of embroidered electrodes also eliminates the requirement for conventional adhesive gel electrodes, which may improve comfort during repeated or extended use. The observed stabilization of ECG signals within approximately 30 seconds further indicates that the textile electrodes can establish effective skin contact without requiring complex preparation.

An important aspect of the developed garment is the integration of the protective polyethylene layer. The layer provided a physical barrier against sweat and moisture and therefore increased protection of the embedded electronic components. However, the air permeability results revealed a trade-off between environmental protection and breathability. Air permeability decreased from 400 L/m²/s for the base fabric to 350 L/m²/s after embroidery and further to 80 L/m²/s after integration of the polyethylene backing layer. Therefore, future garment designs should consider localized or patterned protective layers rather than covering large areas of the garment. Such an approach could maintain moisture protection around the electronics while preserving airflow through the remaining textile regions.

Despite the promising performance of the developed smart textile ECG garment, several limitations should be considered. First, the present evaluation was conducted under resting and mild-activity conditions, while stronger motion conditions were not extensively investigated. Since motion artifacts can affect textile-based ECG measurements, future experiments should evaluate the garment during walking, running, bending, and other daily activities. A larger number of participants would also provide more representative information regarding electrode-skin contact, signal quality, and wearer comfort.

Second, the washability assessment was limited to repeated hand-wash and air-dry cycles, with the present study demonstrating functionality for up to 10 washing cycles. Further studies should investigate long-term durability under a larger number of washing cycles and different washing conditions. In addition, the polyethylene protective layer substantially reduced air permeability in the covered region. Future designs could therefore investigate alternative breathable waterproof membranes, localized protective coatings, or flexible encapsulation techniques that provide moisture protection without substantially reducing garment breathability.

Future work may also focus on miniaturizing the electronic module and integrating more flexible interconnections between the embroidered electrodes and sensing circuit. Wireless transmission and smartphone-based monitoring could be further developed to enable continuous remote ECG monitoring. In addition, advanced signal-processing or machine-learning techniques could be incorporated to automatically identify abnormal ECG patterns and distinguish physiological signals from motion-related noise. These developments could improve the practical applicability of the smart textile platform for long-term home-based health monitoring.

V. CONCLUSION

The developed smart textile ECG garment successfully integrates embroidered Cu-Zn-coated aramid electrodes, wireless ECG sensing electronics, and protective materials to offer a reliable and wearable solution for continuous heart monitoring. The electrodes demonstrated low resistance, high durability, and excellent skin comfort, maintaining stable signal acquisition even after multiple wash and wear cycles. Signal quality tests confirmed clear PQRST waveform detection and acceptable signal-to-noise ratios, with reliable heart rate tracking in both resting and mildly active conditions. The inclusion of a polyethylene backing layer provided effective water and sweat resistance, protecting embedded electronics without significantly compromising comfort. Although air permeability decreased in covered areas, the overall garment remained breathable and suitable for extended wear. This smart garment offers precise, comparable signal performance while improving reusability and user comfort. User feedback further validated its ease of use and quick signal stabilization. Therefore, this study demonstrates that the embroidered smart textile ECG system is a viable, washable, and user-friendly platform for remote cardiac health monitoring, particularly in everyday and home-based settings.

REFERENCES

- [1] J. Löfhede, F. Seoane, and M. Thordstein, "Textile electrodes for EEG recording—A pilot study," *Sensors*, vol. 12, no. 12, pp. 16907-16919, 2012.
- [2] A. Shafiq, R. R. Manero, A. Borg, K. Althoefer, and M. J. Howard, "Designing embroidered electrodes for wearable surface electromyography," in 2016 IEEE international conference on robotics and automation (ICRA), 2016: IEEE, pp. 172-177.
- [3] S. D. Min, Y. Yun, and H. Shin, "Simplified structural textile respiration sensor based on capacitive pressure sensing method," *IEEE Sensors Journal*, vol. 14, no. 9, pp. 3245-3251, 2014.
- [4] D. Pani, A. Achilli, and A. Bonfiglio, "Survey on textile electrode technologies for electrocardiographic (ECG) monitoring, from metal wires to polymers," *Advanced Materials Technologies*, vol. 3, no. 10, p. 1800008, 2018.
- [5] M. Alt Murphy et al., "An upper body garment with integrated sensors for people with neurological disorders—early development and evaluation," *BMC Biomedical Engineering*, vol. 1, pp. 1-13, 2019.
- [6] A. Ankhilli, X. Tao, C. Cochrane, D. Coulon, and V. Koncar, "Washable and reliable textile electrodes embedded into underwear fabric for electrocardiography (ECG) monitoring," *Materials*, vol. 11, no. 2, p. 256, 2018.
- [7] I. C. Van Gelder et al., "2024 ESC Guidelines for the management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS) Developed by the task force for the management of atrial fibrillation of the European Society of Cardiology (ESC), with the special contribution of the European Heart Rhythm Association (EHRA) of the ESC. Endorsed by the European Stroke Organisation (ESO)," *European Heart Journal*, p. ehael176, 2024.
- [8] T. Machino, K. Aonuma, Y. Komatsu, H. Yamasaki, M. Igarashi, A. Nogami, and M. Ieda, "Dry textile electrode for ambulatory monitoring after catheter ablation of atrial fibrillation: A pilot study of simultaneous comparison to the Holter electrocardiogram," *F1000Research*, vol. 11, p. 97, 2022.
- [9] P. L. Rajbhandary, G. Nallathambi, N. Selvaraj, T. Tran, and O. Colliou, "ECG signal quality assessments of a small bipolar single-lead wearable patch sensor," *Cardiovascular Engineering and Technology*, vol. 13, no. 5, pp. 783-796, 2022.
- [10] J. Pagola et al., "Intensive 90-day textile wearable holter monitoring: an alternative to detect paroxysmal atrial fibrillation in selected patients with cryptogenic stroke," *Heart and Vessels*, vol. 38, no. 1, pp. 114-121, 2023.
- [11] T. Machino et al., "Randomized crossover trial of 2-week Garment electrocardiogram with dry textile electrode to reveal instances of post-ablation recurrence of atrial fibrillation underdiagnosed during 24-hour Holter monitoring," *PloS one*, vol. 18, no. 2, p. e0281818, 2023.
- [12] A. B. Nigusse, B. Malengier, D. A. Mengistie, A. Maru, and L. Van Langenhove, "Investigating textile-based electrodes for ECG monitoring in veterinary clinical practice," *AUTEX Research Journal*, vol. 23, no. 4, pp. 551-559, 2023.
- [13] C. Vidhya, Y. Maithani, and J. P. Singh, "Recent advances and challenges in textile electrodes for wearable biopotential signal monitoring: A comprehensive review," *Biosensors*, vol. 13, no. 7, p. 679, 2023.
- [14] A. B. Nigusse, D. A. Mengistie, B. Malengier, G. B. Tsegghai, and L. V. Langenhove, "Wearable smart textiles for long-term electrocardiography monitoring—A review," *Sensors*, vol. 21, no. 12, p. 4174, 2021.
- [15] S. A. Lubitz et al., "Screening for atrial fibrillation in older adults at primary care visits: VITAL-AF randomized controlled trial," *Circulation*, vol. 145, no. 13, pp. 946-954, 2022.
- [16] M. K. Christensen et al., "The cost of mental disorders: a systematic review," *Epidemiology and psychiatric sciences*, vol. 29, p. e161, 2020.
- [17] M. E. Canavan et al., "Psychological distress in Ghana: associations with employment and lost productivity,"

- International Journal of Mental Health Systems, vol. 7, pp. 1-9, 2013.
- [18] N. Long, Y. Lei, L. Peng, P. Xu, and P. Mao, "A scoping review on monitoring mental health using smart wearable devices," *Math. Biosci. Eng.*, vol. 19, no. 8, pp. 7899-7919, 2022.
- [19] Moshayedi, A. J., Khoojine, A. S., Khan, A. S., Roy, A. S., Dangling, X., Xie, Y., ... & Andani, M. E. (2026). EFM2: An Enhanced Sensor Fusion and Path-Tracking Control Framework for Omnidirectional Automated Guided Vehicles. *Journal of Robotics Research (JRR)*, 3(2).
- [20] S. K. Khare, V. M. Gadre, and U. R. Acharya, "ECGPsychNet: an optimized hybrid ensemble model for automatic detection of psychiatric disorders using ECG signals," *Physiological Measurement*, vol. 44, no. 11, p. 115004, 2023.
- [21] J. Bengtsson, R. Bodén, E. Olsson, J. Mårtensson, M. Gingnell, and J. Persson, "Autonomic modulation networks in schizophrenia: The relationship between heart rate variability and functional and structural connectivity in the brain," *Psychiatry Research: Neuroimaging*, vol. 300, p. 111079, 2020.
- [22] Moshayedi, A. J., Khan, A. S., Khan, Z. H., Khoojine, A. S., & Razi, A. (2025). Road space rationing using vehicle's automated license plate recognition: A comprehensive survey of methods. *Applied Neural Networks in the AI Era: From Theory to Real-World Impact*, 93-136.
- [23] Khan, A. S., Rahman, A., & Moshayedi, A. J. (2025). Pipeline Surface Defect Detection Using YOLOv11 with Attention Mechanisms: A Comparative Study of SA, LKA, and CBAM Approaches. *Journal of Robotics Research (JRR)*, 2(2).
- [24] R. Markiewicz, A. Markiewicz-Gospodarek, and B. Dobrowolska, "Galvanic skin response features in psychiatry and mental disorders: A narrative review," *International journal of environmental research and public health*, vol. 19, no. 20, p. 13428, 2022.
- [25] Moshayedi, A. J., Khan, A. S., Jawadi, M. J., Kolahdooz, A., & Emadi Andani, M. (2026). Ergonomically designed assistive robots: Where and how to bring comfort, safety, and independence to elderly care. *Journal of Field Robotics*, 43(4), 2965-2989.
- [26] S. Shahub, S. Upasham, A. Ganguly, and S. Prasad, "Machine learning guided electrochemical sensor for passive sweat cortisol detection," *Sensing and Bio-Sensing Research*, vol. 38, p. 100527, 2022.
- [27] Moshayedi, A. J., Khan, A. S., Davari, M., Mokhtari, T., & Andani, M. E. (2024). Micro robot as the feature of robotic in healthcare approach from design to application: The state of art and challenges. *EAI Endorsed Trans. AI and Robotics*, 3, 1-16.
- [28] Khan, A. S., & Zhang, J. (2025). Lightweight AI for Cultural Pattern Recognition: Safeguarding South Asian Regional Embroidery Heritage. In *Artificial Intelligence and Applications*.
- [29] C. Romano, D. Lo Presti, S. Silvestri, E. Schena, and C. Massaroni, "Flexible Textile Sensors-Based Smart T-Shirt for Respiratory Monitoring: Design, Development, and Preliminary Validation," *Sensors*, vol. 24, no. 6, p. 2018, 2024.
- [30] Moshayedi, A. J., Khan, Z., Wang, Z., & Emadi Andani, M. (2026). IoTToe: Monitoring Foot Angle Variability for Health Management and Safety. *Mathematical and Computational Applications*, 31(1), 13.
- [31] Xu, G., Khan, A. S., Moshayedi, A. J., Zhang, X., & Shuxin, Y. (2022). The object detection, perspective and obstacles in robotic: a review. *EAI Endorsed Transactions on AI and Robotics*, 1(1), 1-10.