Proceedings of the 8th International Conference on Energy Harvesting, Storage, and Transfer (EHST 2025)
July 15, 2025 - July 17, 2025 | Imperial College London Conference, London, United Kingdom
Paper No. 142
DOI: 10.11159/ehst25.142

Flexible Piezoelectric Wrist Brace for Self-Powered Tracking of Wrist Motion Under Weightlifting Load

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Abstract- We present a self-powered smart wrist brace that integrates piezoelectric sensors to enable real-time monitoring of wrist motion during weightlifting. The system incorporates a flexible PVDF film embedded within a custom-fitted brace to convert mechanical strain into voltage signals during wrist flexion. Experiments were conducted with male and female participants under three loading conditions (0, 0.5, and 1.0 kg). The acquired voltage signals were analyzed to assess angle-dependent trends and load responsiveness. Results demonstrated a consistent increase in voltage output with both wrist angle and external load, confirming the device's potential as a lightweight, low-power solution for injury prevention, rehabilitation, and athletic performance monitoring.

***Keywords*:** Piezoelectric sensor; Energy harvesting; Wrist brace, Weightlifting
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1. Introduction

Wrist injuries caused by poor biomechanics are a persistent concern in both athletic and occupational environments. Strength training and resistance exercises, in particular, place the wrist joint under repeated stress through flexion, extension, and deviation movements. Improper technique or overloading can result in repetitive strain injuries (RSIs), ligament sprains, or tendinitis, conditions that often require extended recovery and significantly impact performance [1-3]. This challenge is especially relevant in unsupervised or recreational training, where form correction is limited.

Traditionally, injury prevention has relied on coaching cues, visual assessment, or video analysis. While effective in some scenarios, these methods lack real-time responsiveness and are often inaccessible to general users [4]. In recent years, wearable devices have emerged as powerful tools for movement monitoring. These systems use embedded sensors to measure joint angles, motion patterns, and applied loads, providing actionable data for feedback, injury avoidance, and rehabilitation guidance [5,6].

Modern wearable systems increasingly leverage flexible electronics such as inertial sensors, strain gauges, and capacitive elements. However, most are still powered by batteries or external units, which add bulk and require regular maintenance [7]. This limits their practicality for long-term, real-world use.

To overcome these limitations, there is growing interest in integrating energy-harvesting technologies into wearables. Among these, piezoelectric materials, particularly polyvinylidene fluoride (PVDF), have shown strong potential. They generate electrical signals in response to mechanical deformation, enabling devices to both sense movement and self- power low-energy circuits. Their lightweight, flexible nature makes them ideal for conformal wearable applications [8-10]. Recent studies by Donyaparastlivari et al. and Alghamaz et al. have demonstrated how piezoelectric and hybrid sensor systems can successfully track joint motion and loading without the need for traditional power sources [11,12].

Several recent studies have explored innovative approaches to enhance the performance and versatility of self-powered wearable sensors. Lee et al. compared piezoelectric and triboelectric sensing mechanisms in motion monitoring and highlighted the benefits of piezoelectric materials for reliable, real-time signal acquisition in dynamic conditions [13]. Kim et al. further improved sensor sensitivity by introducing crumpled PVDF film architectures, which significantly enhanced strain detection without compromising flexibility [14]. Similarly, Du, Lei, et al. demonstrated the use of piezoelectric nanogenerators for continuous biomechanical monitoring and interactive human–machine interfaces, showing the promise of energy-harvesting wearables for broader healthcare and robotic applications [15]. In another study by Siddiqui, Saqib, et al., A high-performance, lead-free nanocomposite piezoelectric nanogenerator based on BT nanoparticle-reinforced P(VDF–TrFE) was shown to produce up to 9.8 V and 13.5 µW/cm² under bending, demonstrating strong potential for biomechanical energy harvesting and micro battery charging applications [16]. These advancements underscore the growing potential of piezoelectric materials to serve both as sensors and power sources in next-generation wearable systems.

Despite this progress, few systems have been specifically designed to monitor the biomechanics of the wrist under load, bearing conditions, a notable gap given the wrist's complexity and vulnerability during activities like weightlifting. This study addresses that need by presenting a self-powered smart wrist brace with embedded PVDF sensors. The device captures angular flexion under various resistance levels (0, 0.5, and 1.0 kg) by converting strain into voltage signals. Through experimental calibration with male and female participants, we demonstrate the system's sensitivity, repeatability, and potential utility for real-time feedback in strength training, rehabilitation, and ergonomic assessment.

2. Materials and Methods:

The smart wrist brace was fabricated using soft satin fabric to provide comfort and preserve wrist mobility during flexion. A piezoelectric PVDF strip (50 mm × 10 mm) was embedded into a stitched pocket aligned with the wrist joint, where mechanical strain is most concentrated. The sensor was encapsulated in plastic to ensure durability and insulation, allowing consistent voltage generation in response to joint motion.

Experimental testing was conducted on two healthy participants, one male and one female, both 18 years old. Each subject wore the brace and performed controlled wrist flexion while holding dumbbells under three loading conditions: 0 kg, 0.5 kg, and 1.0 kg. A manual goniometer was used to set wrist angles in 10-degree increments from 0° to 60°. At each position, the participant briefly held the posture while the voltage output was recorded.

Figure 1 illustrates the complete experimental setup. The PVDF sensor was connected to a Siglent SDS1202X-E digital oscilloscope, which captured real-time voltage waveforms throughout the motion trials. All signals were exported and analyzed in MATLAB to extract root-mean-square (RMS) values and assess angle-dependent sensor behavior. All tests were carried out in a controlled laboratory environment. The wrist brace was adjusted between subjects to ensure proper fit and consistent sensor positioning for each trial.

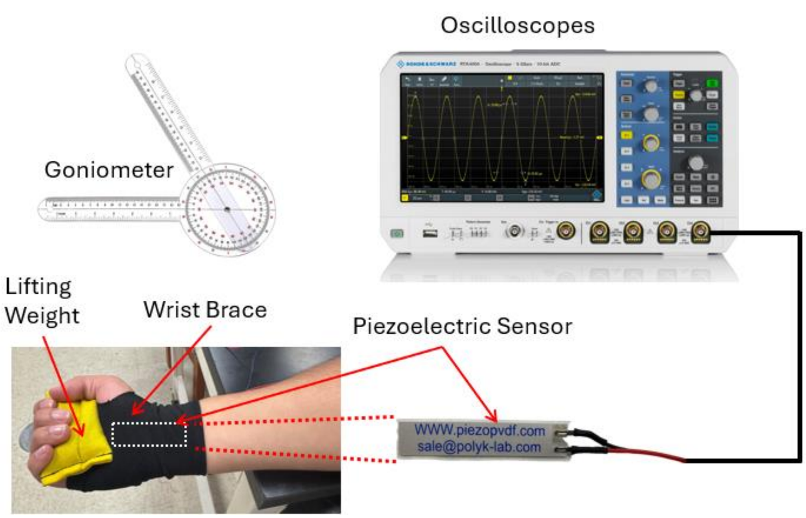

Figure 1Schematic of the experimental setup showing the custom-fabricated smart wrist brace with integrated piezoelectric sensor, goniometer for angular calibration, and oscilloscope for real-time voltage signal monitoring during wrist movement under load.

3. Results and Discussion:

Figure 2 displays sample voltage waveforms collected from the smart wrist brace during wrist flexion and extension performed by both participants. Two angles were analysed: 10° in the top subplot and 50° in the bottom subplot. The female participant's signals appear in blue, and the male participant's signals are shown in red. Circular and square markers were used to distinguish between the two datasets. All signals were aligned to begin at time t = 0 seconds to enable direct comparison of waveform shape and dynamic behaviour.

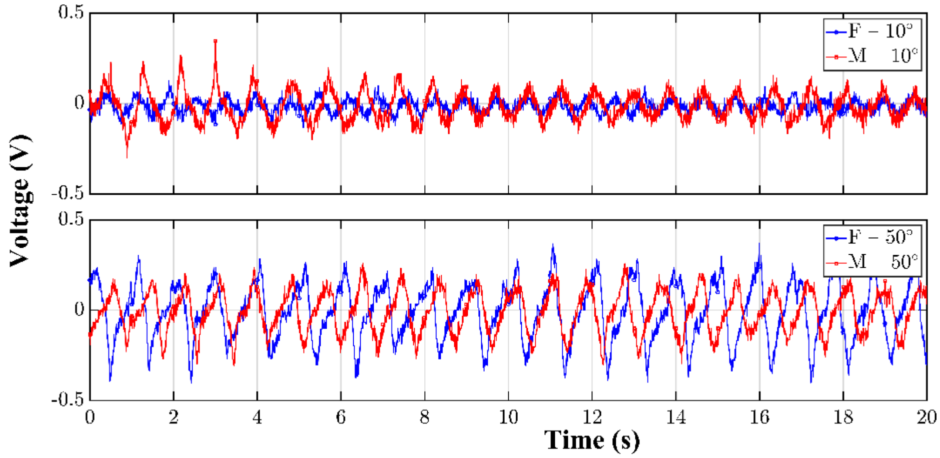

Figure 2: Sample of the time-domain voltage signals under no loading conditions from male and female participants at 10° wrist angle (top) and 50° wrist angle (bottom).

At 10°, both participants produced low-amplitude voltage signals with consistent rhythmic patterns, reflecting the regular motion of the wrist. These smaller outputs are expected at low flexion angles, where the mechanical deformation of the sensor is minimal. The overall waveform shapes were similar between participants, although the male participant showed slightly higher peak-to-peak values, which could be related to differences in muscle tone or joint stiffness.

At 50°, the voltage signals increased noticeably for both participants, indicating a higher level of strain applied to the sensor during greater wrist flexion. The female participant's waveform showed sharper peaks and more variability, while the male participant's signal was more uniform and periodic. This difference may reflect variations in how each individual controls wrist motion or distributes force. Despite these differences, both participants exhibited clear signal patterns that varied with joint angle, confirming the sensor's ability to detect personalized mechanical responses. The next sections present the experimental findings using bar plots. This format provides a clear and direct view of how voltage output changes with wrist angle and load.

3.1. No Load Condition:

To measure wrist flexion without the influence of added resistance, voltage signals were recorded from the piezoelectric sensors under no-load conditions. Both the female and male participants performed repeated flexion movements at six preset angles: 10°, 20°, 30°, 40°, 50°, and 60°. Each target angle was held multiple times during a continuous recording session. The root-mean-square (RMS) voltage was then calculated for each angle to evaluate the sensor's response.

Figure 3 presents the data from the female participant. The results show a gradual increase in voltage as the wrist angle increases, reflecting the expected rise in mechanical strain. A slight nonlinear trend is noticeable beyond 40°, which may be due to additional deformation of the piezoelectric layer under higher levels of flexion.

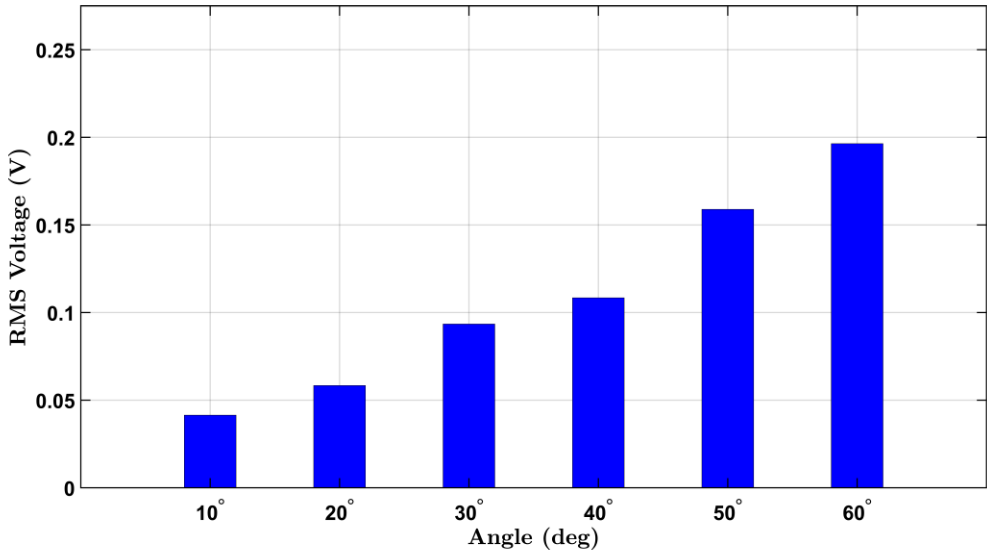

Figure 3: No-load RMS voltage response of the female participant across six wrist flexion angles.

Figure 4 shows the corresponding results for the male participant. The data follow a similar increasing pattern across all six wrist angles, with slightly higher RMS voltage values compared to the female participant. These differences may be influenced by individual factors such as wrist structure, muscle tension, or movement mechanics. The overall trend is consistent with how piezoelectric sensors respond to mechanical bending, confirming the sensor's ability to detect variations in strain based on angular displacement.

These no-load measurements establish a useful reference point for comparing the sensor's response under applied loads. They also serve as a baseline for future calibration and normalization of voltage outputs across different conditions.

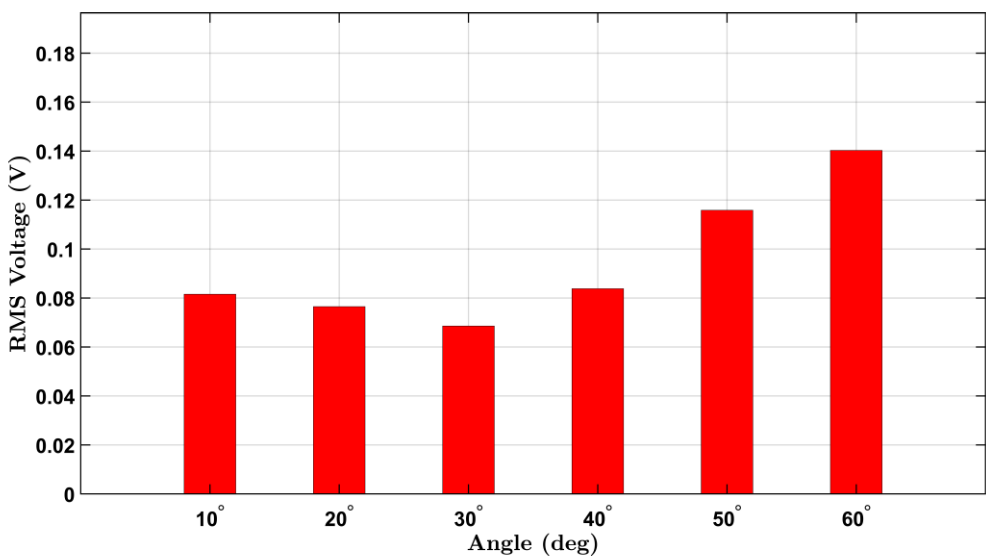

Figure 4: No-load RMS voltage response of the male participant across six wrist flexion angles.

3.2 0.5 kg Load Condition:

To investigate how external load influences sensor response, wrist flexion tests were performed under a 0.5 kg weight for both participants. RMS voltage values were extracted from time-domain signals recorded at six wrist angles, ranging from 10° to 60°. The results are presented in Figures 5 and 6.

As shown in the figures, both participants experienced a general rise in voltage as the flexion angle increased. This is consistent with the behaviour of piezoelectric materials, where greater angular displacement causes more mechanical strain, leading to higher electrical output.

For the female participant, voltage peaked at 50° and 60°, with values higher than those recorded during the no-load condition shown in Figure 3. A noticeable increase also occurred between 20° and 30°, possibly reflecting improved joint engagement or muscle activation under moderate load. At lower angles, such as 10°, the voltage remained similar to the baseline condition, which may be due to limited sensor strain at small joint movements.

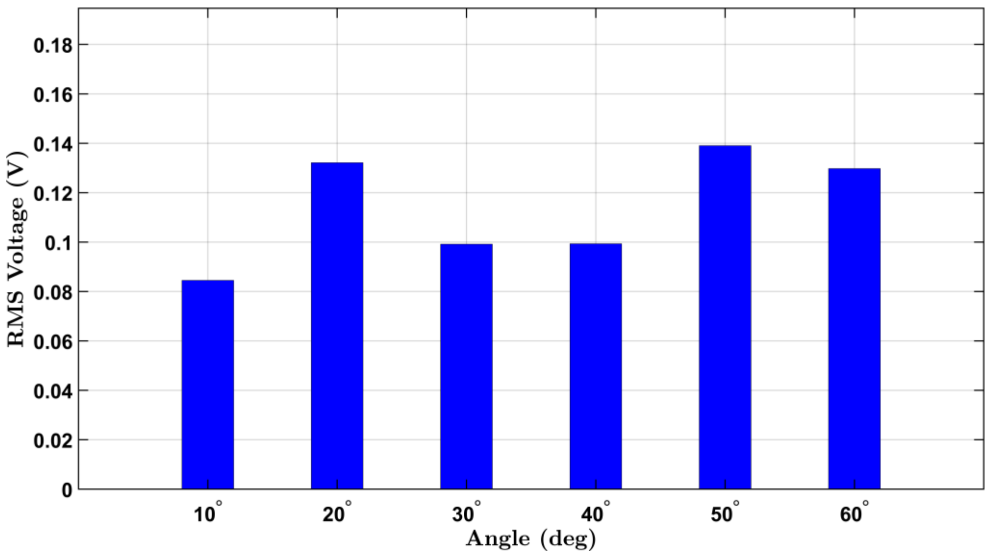

Figure 5: RMS voltage response of the female participant at 0.5 kg load across six wrist flexion angles.

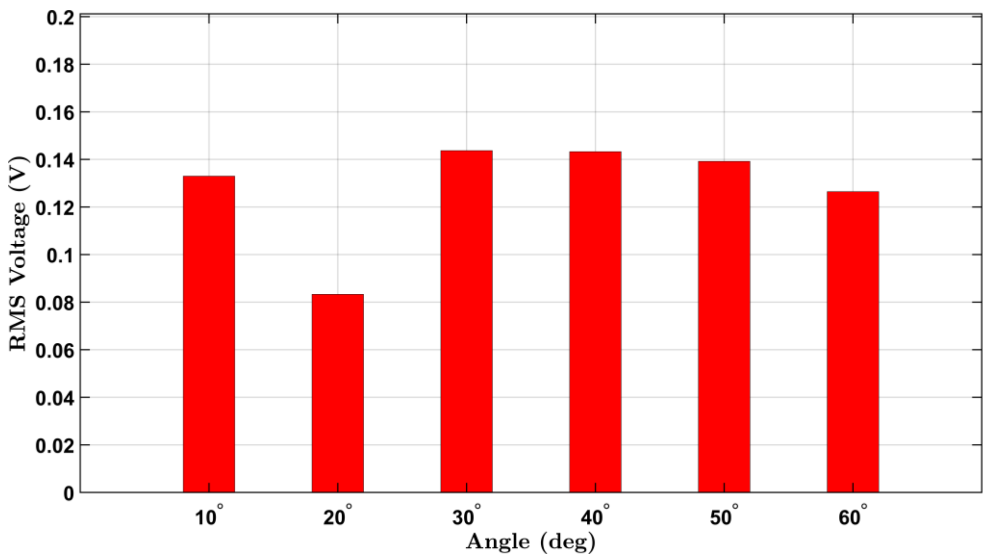

Figure 6: RMS voltage response of the male participant at 0.5 kg load across six wrist flexion angles.

3.2 1.0 kg Load Condition:

Figures 7 and 8 show the RMS voltage readings collected from the female and male participants, respectively, during wrist flexion with a 1.0 kg external load. Each bar in the plot represents the average voltage produced by the sensor at angles from 10° to 60° during repeated wrist movements.

For the female participant (Figure 7), the data show a clear and steady increase in voltage with wrist angle, reaching a peak above 0.25 V at 60°. This strong upward trend indicates that larger flexion angles, when combined with heavier loading, create more strain on the sensor and result in higher electrical output. Compared to lower loading conditions, the 1.0 kg case yields a sharper voltage slope and greater absolute values, reflecting the sensor's responsiveness to increased mechanical input.

The male participant's results (Figure 8) also follow a rising trend, with voltage values increasing across the tested angles. His signal peaks at around 0.21 V at 60°, showing a gradual and consistent rise from 10°. The voltage difference between 0.5 kg and 1.0 kg loads is more noticeable than the change between no load and 0.5 kg, suggesting a nonlinear effect of load on strain response. Although the male participant's voltage outputs are slightly lower than the female's at most angles, the difference becomes smaller at higher loads, possibly due to variations in muscle mass, wrist anatomy, or how the brace conforms to each individual.

Overall, these findings reinforce that the smart wrist brace effectively captures biomechanical strain changes that depend on both flexion angle and external load. The consistent voltage increases across all loading conditions highlights the system's reliability for tracking joint mechanics in resistance-based training and rehabilitation contexts.

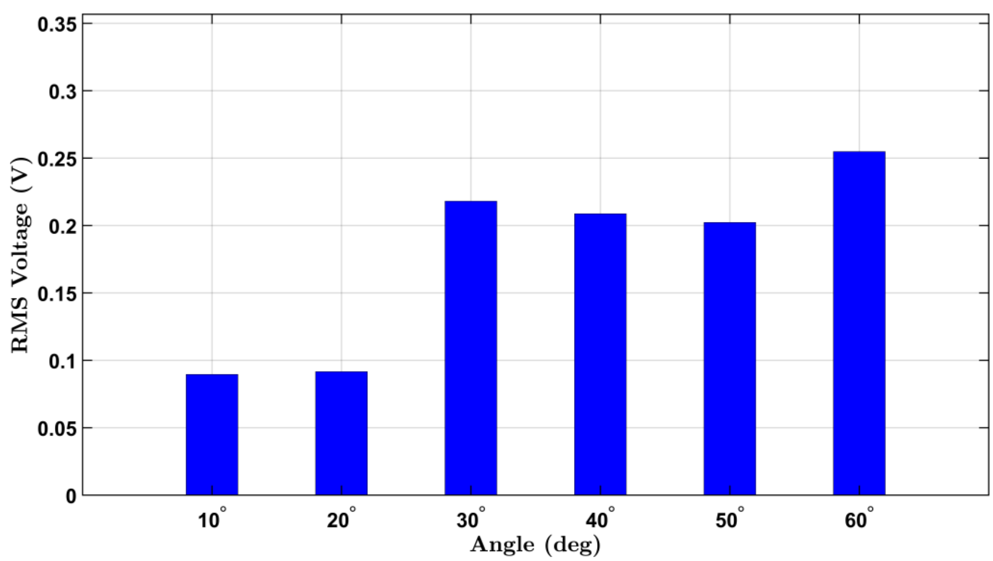

Figure 7: RMS voltage response of the female participant during wrist flexion under a 1.0 kg load across six target angles.

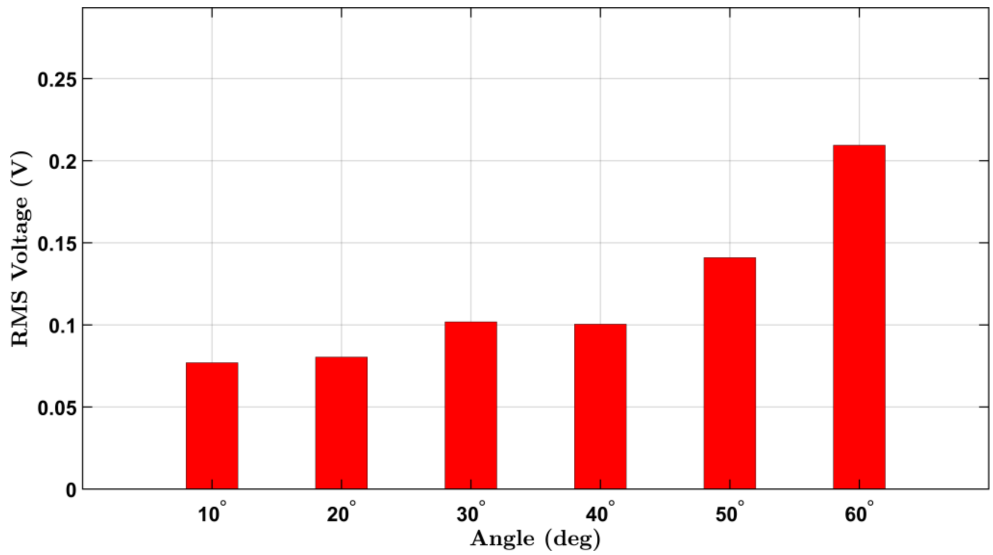

Figure 8: RMS voltage response of the male participant during wrist flexion under a 1.0 kg load across six target angles.

4. Conclusion:

The results presented in this study demonstrates the effectiveness of a piezoelectric-integrated smart wrist brace in tracking wrist flexion during weightlifting. For both male and female participants, voltage output increased consistently with flexion angle and external load, highlighting a clear relationship between biomechanical strain and electrical response. Across all three loading conditions, the bar plots revealed distinct and repeatable patterns that reflect the sensor's capability to detect joint motion in real time. These findings support the practical use of the smart brace for monitoring wrist mechanics during resistance-based movements. The consistent trends captured in the bar charts affirm the system's potential as a lightweight, low-power tool for motion assessment in training, rehabilitation, or ergonomic evaluation.

5. References:

1. W. C. Whiting and R. F. Zernicke, Biomechanics of Musculoskeletal Injury, 2nd ed., Human Kinetics, 2008.
2. J. W. Keogh and D. W. Winwood, "The epidemiology of injuries in powerlifting," *Journal of Science and Medicine in Sport*, vol. 13, no. 5, pp. 397–405, 2010.
3. L. Gordon and M. B. Jariwala, "Upper limb injuries in weight training: diagnosis and management," *British Journal of Sports Medicine*, vol. 42, no. 3, pp. 207–210, 2008.
4. A. Fitzpatrick, "Coaching practices in amateur weightlifting: the importance of real-time feedback," *International Journal of Coaching Science*, vol. 12, no. 1, pp. 101–118, 2018.
5. P. Bonato, "Advances in wearable technology and applications in physical medicine and rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 2, p. 2, 2005.
6. J. Taborri, A. Palermo, and S. Rossi, "A survey on wearable sensor-based systems for health monitoring and rehabilitation," *Sensors*, vol. 20, no. 15, p. 4141, 2020.
7. Y. Lu, Y. Jiang, and W. Feng, "Flexible and stretchable electronics for biointegrated devices," *Advanced Functional Materials*, vol. 29, no. 51, p. 1904379, 2019.
8. A. Fedaa, L. Donyaparastlivari, S. A. Ghorshi, A. Zabihollah, and A. Ibrahim, "Integrating piezoelectric sensors for enhanced failure prediction of residential buildings in hurricane," *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems*, 2024.

9. F. Ali, L. Donyaparastlivari, S. Ghorshi, A. Zabihollah, M. Alghamaz, and A. Ibrahim, “Feasibility Study of Signal Processing Techniques for Vibration-Based Structural Health Monitoring in Residential Buildings,” *Sensors*, vol. 25, no. 7, p. 2269, 2025.
10. M. Alghamaz, L. Donyaparastlivari, and A. Ibrahim, “Dynamic Response and Energy Conversion of Coupled Cantilevers with Dual Piezoelectric–Triboelectric Harvesting Mechanisms,” *Micromachines*, vol. 16, no. 2, p. 182, 2025.
11. L. Donyaparastlivari, M. Atmeh, P. Indic, and A. Ibrahim, “A feasibility analysis of triboelectric energy harvester for hip implants,” in *2023 IEEE 16th Dallas Circuits and Systems Conference (DCAS)*, pp. 1–4, 2023.
12. Wang, X., Liu, Z. and Zhang, T., 2017. Flexible sensing electronics for wearable/attachable health monitoring. Small, 13(25), p.1602790.
13. Y. Lee, S. Park, and H. Kim, “Self-powered wearable sensors for monitoring human motion: Piezoelectric versus triboelectric mechanisms,” *Advanced Materials*, vol. 29, no. 6, p. 1605973, 2017.
14. Cao, Y., Guo, Y., Chen, Z., Yang, W., Li, K., He, X. and Li, J., 2022. Highly sensitive self-powered pressure and strain sensor based on crumpled MXene film for wireless human motion detection. Nano Energy, 92, p.106689.
15. Du, L., Li, Y., Qiu, R., Xu, J., Nie, K., Cao, X., Tang, J., Wang, Y., Du, G. and Bu, L., 2024. Recent advances in piezoelectric and triboelectric self-powered sensors for human-machine interface applications. Journal of Micromechanics and Microengineering.
16. Siddiqui, S., Kim, D.I., Nguyen, M.T., Muhammad, S., Yoon, W.S. and Lee, N.E., 2015. High-performance flexible lead-free nanocomposite piezoelectric nanogenerator for biomechanical energy harvesting and storage. Nano Energy, 15, pp.177-185.