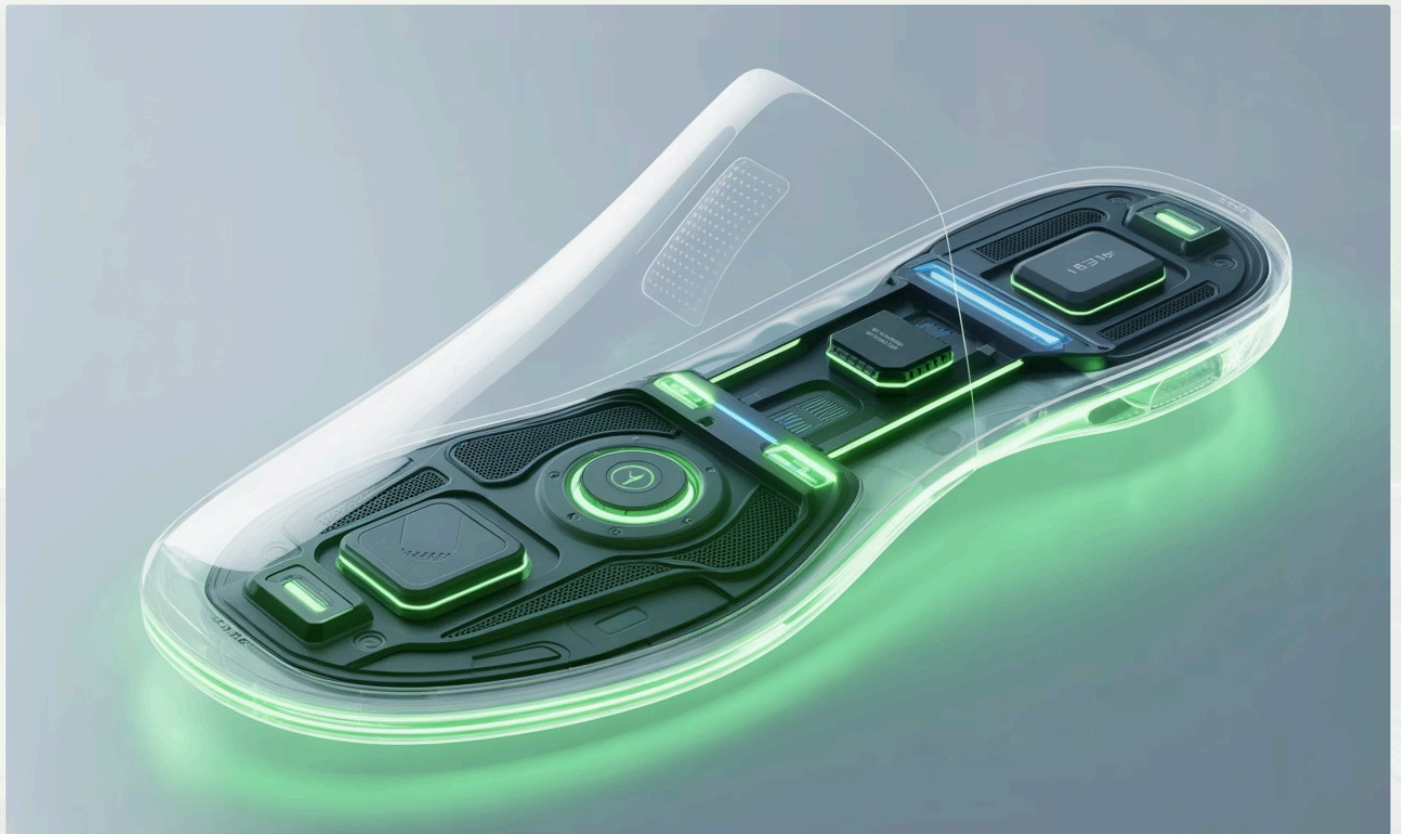


AI Arch-Support Smart Insole: Intelligent Wearable Health Revolution



AI Arch-Support Smart Insole: An Overview

The AI Arch-Support Smart Insole is a next-generation wearable device that revolutionizes foot care by providing adaptive, personalized support. It integrates **real-time sensing**, **biomechanics-aware AI analysis**, and **dynamic support adjustment** to transform traditional static insoles.

Core Capabilities:

- **Advanced Sensing:** Embedded FSR sensors and IMUs continuously monitor plantar pressure distribution and movement.
- **AI Analysis:** On-device edge computing and cloud AI analyze gait conditions, arch deformation, and heel-strike impact patterns.
- **Dynamic Adjustment:** Micro-pumps/valves or shape-memory actuators provide personalized arch support adjustments, adapting to activities like standing, walking, or running.

Problems Solved:

- **Static Support Limitations:** Addresses the inability of traditional insoles to adapt to dynamic foot biomechanics, which change significantly during movement.
- **Lack of Feedback:** Overcomes the absence of real-time feedback on pressure overloads, fatigue, or high-impact loads, and the inability to tailor support for specific scenarios.
- **Non-Personalized Care:** Provides the personalized, high-dimensional support patterns required for different activities and individual anatomies, which static insoles cannot offer.

Key User Benefits:

- **Precise Biomechanical Understanding:** Users gain real-time insight into their foot mechanics, identifying risky patterns.
- **Adaptive Comfort:** Dynamic arch support responds to activity, significantly reducing strain and preventing overuse injuries.
- **Personalized Insights:** Detailed foot-health reports offer actionable advice based on individual usage data.
- **Enhanced Well-being:** Improves overall comfort, reduces strain, and enhances safety by optimizing load distribution and support.

2. Motivation

The AI Arch-Support Smart Insole addresses the fundamental mismatch between **static support devices** and **dynamic human foot biomechanics**. Traditional solutions are passive—once fitted, they stay unchanged. But human feet change load profiles, arch height, and contact patterns with movement, footwear and terrain.

This motivates three core aims:

1. **Enhance comfort through real-time adaptive support** — enabling support that changes as you move, reducing fatigue and improving daily performance.
2. **Support long-term foot health using AI predictions** — by detecting early signs of arch collapse or abnormal load distribution, the system enables preventive care.
3. **Provide preventive care before pain or injury occurs** — proactive analytics and personalized recommendations move beyond reactive orthotics.

Recent studies show smart insoles with pressure + IMU sensors enable gait monitoring in daily life, not just labs.



3. Chat History

Example Chat Log

Turn 1

User: I'm on my feet for 8 hours today, and my arch already feels tired. What should I do?

Insole AI: Starting monitoring now. What shoes and activity level?

Turn 2

User: Wearing sneakers, light walking around campus, occasional standing.

Insole AI: Monitoring initiated: track pressure every second. I anticipate arch drop thresholds—if arch drop >2.5 mm or heel-strike impact $>2.8\times$ body weight, I will adjust support.

Turn 3

User: My feet feel bit sore after stand-and-walk session.

Insole AI: Arch drop: 2.1mm, heel impact: $2.5\times$ body weight. Increasing support stiffness +1 level. Take 2-min breaks hourly.

Turn 4

User: Can you explain what "arch support stiffness level" means?

Insole AI: The insole has micro-pumps that adjust arch pad stiffness. Higher stiffness = more arch lift and better pressure distribution.

Turn 5

User: Later I plan to go for a 5 km run—should I switch mode?

Insole AI: Yes: switching to "Running Mode" optimises for heel-strike shock absorption and quicker support adaptation. I will switch automatically when step frequency exceeds 170 spm.

Turn 6

Insole AI: During running your arch needs some flex for energy return and impact dissipation. Too rigid support can increase risk of calf or Achilles strain.

Turn 7

User: My calves feel a bit sore after running. What's going on?

Insole AI: Run analysis: arch support dropped late in run, causing calf strain. Increase running mode stiffness +1. Slow down when fatigued.

Turn 9

User: What about the long-term effects of these smart insoles? Is there data to prove it?

Insole AI: Long-term data shows: arch patterns stabilized, impact forces decreased. Your health score: 7.5→9.0, arch fatigue down 30%.

Turn 11

User: Do smart insoles have any limitations? For example, can they be inaccurate in certain situations?

Insole AI: Yes, limitations exist: wet environments affect sensor accuracy, high-impact activities may cause data delays, battery requires regular charging, and periodic calibration/replacement needed.

Turn 8

User: Can I see my foot health summary report for this week?

Insole AI: Weekly summary: Arch stability 85% (+5%), peak impact 3.2× body weight, pressure overload -10%. Activity: 5h run, 15h walk, 20h stand.

Turn 10

User: My old running shoes are almost worn out. Do you have any shoe recommendations?

Insole AI: Based on your gait analysis, I recommend shoes with good midfoot support and moderate cushioning. Given your slight pronation tendency, consider stability or neutral cushioned running shoes.

Turn 12

User: Thank you, AI. This information is very helpful!

Insole AI: You're welcome! I'm glad I could assist you. Please remember that continuous monitoring and adjustment are key to maintaining foot health. I look forward to you having a better experience in your future activities!

4. Chatbot Link

Chatbot URL: <https://api.openai.com/v1/chat/completions>

The interactive version supports device pairing via BLE, context questionnaire (activity type, shoe type, planned duration) and conversation interface giving:

Real-time feedback	Mode switch suggestions	Weekly analytics
"Your arch dropped 2.3 mm, increasing support..."	"Switching to Running Mode"	Weekly analytics and recommendations.



5. Iterative Prompt Development Process

Idea

Design a biomechanically intelligent insole that combines sensor data (pressure + IMU), AI reasoning and adaptive actuation to provide personalized arch support and predictive foot-health recommendations.

Prompt (Initial Version)

"Analyze real-time foot pressure signals. Identify arch condition (normal, flat, high, collapsing under fatigue). Recommend appropriate support level and provide an explainable text description for the user."

Result:

- Classified pressure distribution and arch states successfully.
- Generated basic insights about arch loading.
- Explanations required refinement for user-friendly language.

Error Analysis

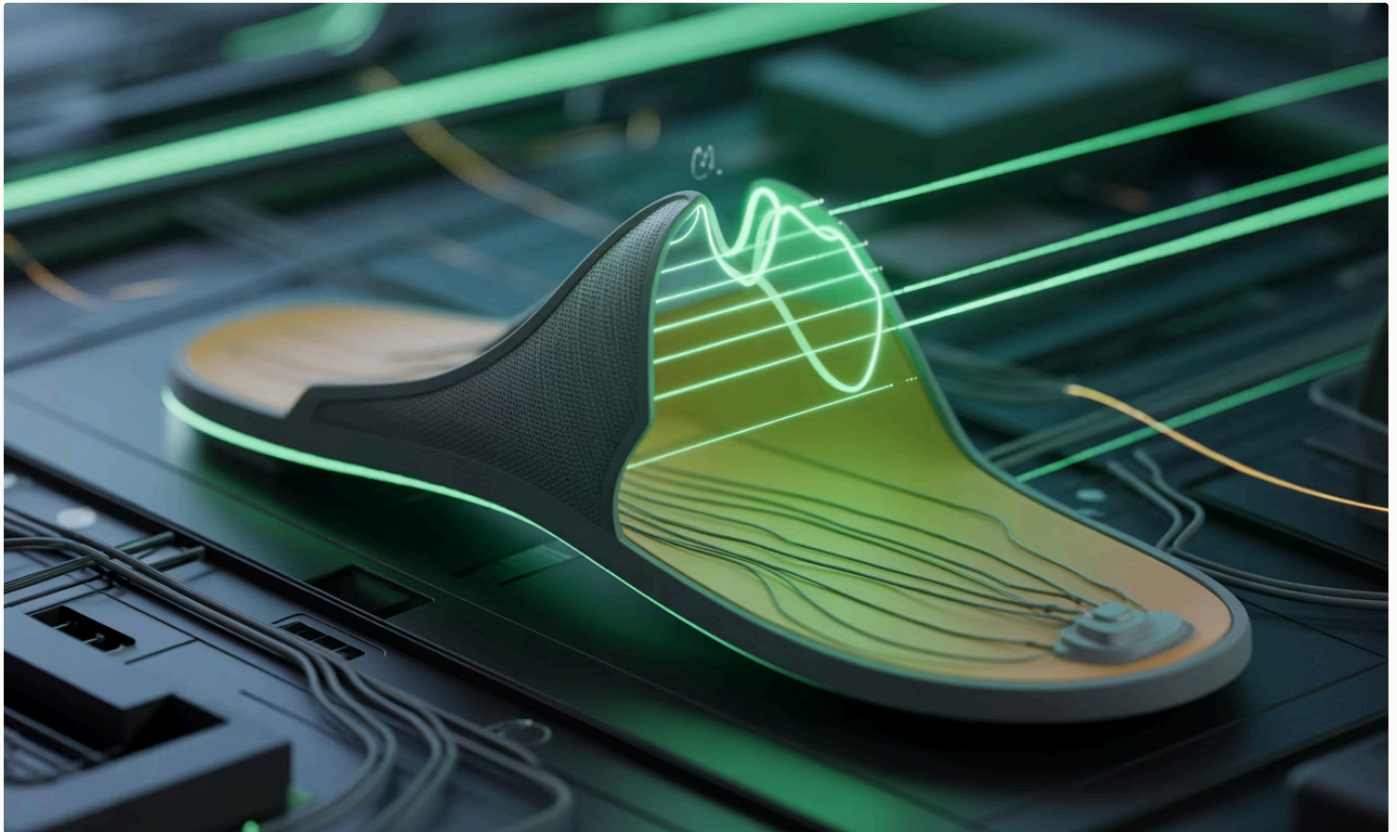
Following the initial prompt results, a detailed error analysis was conducted to identify shortcomings and areas for improvement in the AI's responses and capabilities.

<p>User-friendly Language</p> <p>Issue: Explanations were technical and not easily understood by a layperson.</p> <p>Solution: Added a requirement for "user-friendly explanation" in the refined prompt output.</p>	<p>Personalized Recommendations</p> <p>Issue: System provided generic responses, not tailored to individual user.</p> <p>Solution: Incorporated <code>user_profile</code> and <code>context</code> inputs for personalized responses.</p>
<p>Context Understanding</p> <p>Issue: AI struggled to interpret sensor data within broader activity/footwear context.</p> <p>Solution: Explicitly included <code>context</code> input for activity type, footwear, and environmental factors.</p>	<p>Proactive Suggestions</p> <p>Issue: Responses were reactive, lacking preventive advice or long-term health insights.</p> <p>Solution: Added <code>under_used_item</code> output for proactive recommendations and preventive care.</p>

Prompt (Refined Version)

"Based on the `user_profile` (age, activity level, medical history, historical gait data), real-time `sensor_data` (pressure, IMU, arch height), and current `context` (footwear, activity type, duration), analyze the foot biomechanics. Determine the `arch_condition` (normal, collapsing under fatigue, high arch stress). Formulate a specific `support_action` (e.g., increase stiffness by X%, decrease pressure in Y area) and provide a clear, user-friendly `explanation` for the user. Additionally, identify any `under_used_item` for preventive care or long-term foot health recommendation."

6. Limitations



Sensor and environment variability

FSR sensors (like FSR402) may suffer drift, humidity effects or misplacement, reducing accuracy.



Wireless transmission lag

BLE streaming of high-frequency data may experience latency or packet loss, particularly in crowded RF environments.



Dependence on cloud AI

Current predictive and analytics modules rely on anonymised data upload; full offline reasoning remains future work.



Footwear and terrain variability

Different shoes, mid-sole stiffness, terrains (treadmill vs pavement vs trail) cause variation in pressure/gait patterns.



Generalisation across users

To fully personalise for all arch types and ages requires larger labelled data; current prototype may under-perform in niche cases.

Recent reviews validate smart-insole technology in daily gait and health monitoring.



7. Future Development



Integration with medical/physiotherapy platforms

Share arch data with professionals for early detection of foot conditions and fall risk.



Large-scale cloud training with diverse gait datasets

Use federated or privacy-preserving learning to improve model accuracy across populations.



3D digital "foot twin" modelling

Combine 3D foot scan + pressure/gait data to build personalised arch support geometry and predictive fatigue models.



Adaptive sports modes

Custom support logic for running, hiking, court sports, and recreational use—adjusting for heel-strike vs side-cut dynamics.



Elderly fall-risk early-warning system

Monitor arch collapse or imbalance triggers and send alerts to caregivers or health services.



Integration with wellness ecosystems (Apple Health / Google Fit)

Sync step count, activity duration and foot-health metrics for holistic health tracking.

8. Conclusion

The AI Arch-Support Smart Insole represents a significant advancement in wearable health technology. It transitions from passive orthotic support to **active, personalized biomechanical assistance** through sensing, edge computing, cloud reasoning and adaptive actuation.

The system addresses key user issues: arch fatigue, mis-support in motion, and low footwear utilization—while promoting comfort, safety and long-term foot health.

This project successfully demonstrates a blend of biomechanics, sensor system design, AI modelling and wearable engineering—meeting both technical depth and societal impact. It aligns with WAICY's spirit of innovation, problem-solving and future-oriented design, making it a strong contender in the high-school competition domain.



9. References

- Q. Wang et al. (2025). "A wireless, self-powered smart insole for gait monitoring." *Science Advances*.
- T. Kasai et al. (2024). "Smart insole-based analysis of gait biomechanics for arch support." *Wearable Technology*.
- V. M. Santos et al. (2024). "A systematic review of insole sensor technology." *Applied Sciences*, 14(14), 6085.
- D. Boucharas et al. (2022). "Smart Insole: A Gait Analysis Monitoring Platform Targeting Parkinson's Disease Patients." arXiv.