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Automatic Shoe Shiner: A Low-Cost Electromechanical Assistive Device for Ergonomic Shoe Care

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Abstract

Routine shoe polishing is commonly performed using manual methods that require repeated forward bending, leading to ergonomic strain and discomfort, particularly affecting the back and knees. This study presents the design, scientific basis, and experimental evaluation of an Automatic Shoe Shiner developed as a low-cost, ergonomically optimized electromechanical device for household and community use. The system employs DC motors, controlled rotational motion, and friction-based brushing within a vertical configuration that enables shoe polishing in upright standing or sitting posture. A structured observation-based methodology was adopted to evaluate functional performance, ergonomic comfort, and operational stability under varying conditions. Experimental observations demonstrated uniform polishing performance, reliable low-voltage operation, and a significant reduction in bending-related strain compared to conventional manual methods. Beyond functional utility, the device visibly demonstrates applied physics and biomechanical principles, offering educational value as a hands-on STEM learning model. The Automatic Shoe Shiner highlights the potential of frugal, human-centered innovation to address everyday ergonomic challenges while promoting accessibility, preventive comfort, and practical science education.

Keywords: Automatic Shoe Shiner, Ergonomic Design, Electromechanical Systems, Frugal Innovation, Assistive Devices, Applied Physics in Daily Life

1. Introduction

Daily personal grooming activities play an important role in social interaction, professional appearance, and self-confidence. Shoe polishing is one such routine activity that is commonly performed across households, workplaces, and service environments. Despite its frequency, shoe polishing has received limited attention from an ergonomic and technological perspective. Conventional manual shoe polishing typically requires repeated forward bending or squatting, which places mechanical stress on the lumbar spine and knee joints and may lead to discomfort, fatigue, and long-term musculoskeletal issues.

With growing awareness of ergonomics and preventive health, there is an increasing need to redesign everyday tasks to reduce physical strain and promote user comfort. Although electric shoe-polishing machines are available, their application is largely restricted to commercial settings such as hotels and airports due to high cost, bulky construction, and limited suitability for domestic use. As a result, most individuals continue to rely on manual methods that do not address postural or ergonomic concerns.

Recent advances in frugal engineering and human-centered design have demonstrated that simple, low-cost electromechanical systems can effectively improve usability and comfort in daily activities. Such innovations not only enhance functional efficiency but also increase accessibility, particularly in household and community contexts. Furthermore, everyday devices designed with visible mechanical and electrical elements can serve as effective tools for experiential learning by demonstrating applied physics principles in real-world settings.

In this context, the Automatic Shoe Shiner is proposed as a low-cost, ergonomically optimized electromechanical device that enables shoe polishing in upright standing or sitting posture. This study presents the design, scientific principles, experimental evaluation, and societal relevance of the device, highlighting its potential as both a practical assistive solution and an educational innovation.

2. Problem Statement

Manual shoe polishing is a routine activity that involves repeated forward bending of the body, resulting in ergonomic strain on the lumbar spine and knee joints. Such postural loading is associated with discomfort, fatigue, and an increased risk of musculoskeletal disorders, particularly among elderly individuals and office-goers [3]. Despite the availability of electric shoe-polishing machines, their high cost, bulky design, and commercial orientation limit their suitability for household or small-scale use, forcing users to rely on manual methods that compromise comfort and posture [4].

In addition, most existing shoe-polishing solutions do not incorporate educational value, as they fail to visibly demonstrate applied physics principles such as rotational motion, torque, friction, and electromechanical energy conversion. This highlights the need for a low-cost, ergonomically optimized, and educationally meaningful shoe-polishing device. The Automatic Shoe Shiner is proposed to address this gap by integrating ergonomic design with simple electromechanical automation using affordable components.

3. Literature Review

Previous studies in ergonomics have established that repetitive bending, forward trunk flexion, and non-neutral postures significantly increase stress on the lumbar spine and knee joints, leading to discomfort and musculoskeletal disorders during routine activities. Karwowski and Marras demonstrated that even low-intensity daily tasks involving repeated bending can result in cumulative spinal load and fatigue, highlighting the need for ergonomically optimized task design [3].

To assess and mitigate such risks, posture evaluation frameworks such as Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) have been widely adopted. These methods confirm that tasks requiring frequent bending and awkward postures are associated with elevated musculoskeletal risk and emphasize the importance of ergonomic intervention in manual activities [5], [6].

Recent research has shown that low-cost, human-centered assistive devices can effectively reduce posture-related strain when designed using basic biomechanical and mechanical principles. More demonstrated through the SpinoGear system that frugal, home-based mechanical solutions can provide ergonomic benefits while remaining accessible and user-friendly, thereby reinforcing the feasibility of simple assistive innovations for daily use [7].

In addition, studies in engineering education highlight that hands-on electromechanical systems enhance understanding of applied physics concepts such as motion, force, torque, and energy conversion. Experiential learning through real-world devices has been shown to improve conceptual clarity and engagement compared to purely theoretical approaches [8].

Collectively, the literature indicates a gap in low-cost, portable household devices that simultaneously address ergonomic comfort and educational relevance. This gap forms the basis for the development of the Automatic Shoe Shiner as an ergonomically optimized, electromechanical assistive device with applied science learning potential.

4. Design and Components

The Automatic Shoe Shiner was developed as a low-cost, portable electromechanical device with a primary emphasis on ergonomic comfort, functional simplicity, and ease of fabrication. The design aims to eliminate the need for forward bending during shoe polishing by enabling operation in standing or sitting posture. The overall configuration and component selection were guided by frugal engineering principles and user-centered design considerations, as documented in the author's Raman Award Stage-2 innovation report [1].

4.1. Design Architecture

The system adopts a vertical structural configuration, consisting of a long metal/PVC pipe that serves both as a support column and an ergonomic handle. This vertical orientation aligns the polishing unit with the natural reach of the user's hand and foot, thereby reducing spinal flexion and knee loading during operation. The upper section of the structure functions as a handle for stable grip, while the lower section houses the motor–brush assembly responsible for the polishing action.

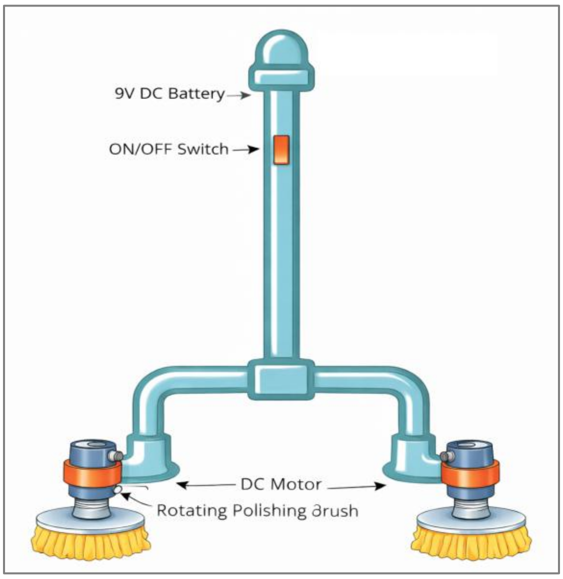

Figure 1: Conceptual design of the Automatic Shoe Shiner showing the vertical structure and motor-brush arrangement

The design is modular in nature, allowing easy assembly, disassembly, and maintenance. Such modularity makes the device suitable not only for household use but also for educational demonstrations and student-led fabrication projects.

4.2. Core Components

The Automatic Shoe Shiner integrates the following key components:

- **DC Motors:** Two low-voltage DC motors are used to generate rotational motion required for shoe polishing. The motors are selected to provide sufficient torque and stable rotational speed, ensuring uniform brushing action without excessive vibration or damage to the shoe surface.
- **Polishing Brush:** A talcum powder or shoe-polishing brush is mechanically coupled to the motor shaft. The rotating brush serves as the primary interface between the device and the shoe, enabling dust removal and polish spreading through controlled friction.
- **Power Supply:** A 9 Volt DC battery is employed as the power source to ensure portability and operational safety. The battery-operated design eliminates dependency on external power outlets, allowing flexible indoor use.
- **Control Switch:** An ON/OFF switch is integrated into the electrical circuit to allow user-controlled activation of the motors. This ensures safe handling and prevents unintended motion during non-operation.
- **Electrical Wiring:** Insulated connecting wires form a simple electrical circuit connecting the battery, switch, and motors. The wiring layout is intentionally kept minimal to reduce complexity.
- **Structural Frame:** The metal/PVC pipe frame provides mechanical stability, maintains alignment of the motor–brush assembly, and absorbs minor operational vibrations. Lightweight materials are chosen to ensure ease of handling while maintaining adequate rigidity.

Figure 2: Prototype of Automatic Shoe Shiner

4.3. Design Rationale

The selection of components prioritizes affordability, availability, and ease of replication using commonly accessible materials. Unlike commercial shoe-polishing machines that rely on complex housings and high-power systems, the proposed design focuses on functional adequacy and ergonomic benefit. The vertical configuration directly supports the ergonomic objective of minimizing bending-related strain.

As demonstrated in the Raman Award Stage-2 project study [1], the design successfully balances mechanical performance with user comfort, illustrating that simple electromechanical systems can effectively address everyday ergonomic challenges while remaining suitable for educational and household applications.

5. Scientific Principles Involved

The functioning of the Automatic Shoe Shiner is governed by fundamental principles of physics and basic engineering, integrating electrical, mechanical, and ergonomic concepts to achieve effective and user-friendly shoe polishing.

5.1. Energy Conversion

The device operates through the conversion of electrical energy into mechanical energy using DC motors. Electrical energy supplied by a 9 V DC battery flows through the motor windings, generating a magnetic field that produces torque on the rotor. This torque results in rotational motion of the motor shaft, which is mechanically coupled to the polishing brushes.

This electromechanical energy conversion enables automated operation while maintaining low power consumption and operational safety, making the system suitable for regular household, commercial, and educational use [1].

5.2. Rotation and Torque

Rotational motion is a critical factor in the effectiveness of the shoe polishing process. The torque produced by the DC motors determines the rotational stability and speed of the polishing brushes. Adequate torque ensures consistent contact between the brush and the shoe surface, resulting in uniform cleaning and polish distribution.

Controlled rotational speed prevents excessive pressure, reduces vibration, and minimizes the risk of surface damage, thereby improving both performance and durability of the device.

5.3. Friction

The polishing mechanism relies on controlled frictional interaction between the rotating brush and the shoe surface. Friction facilitates the removal of dust particles and enables even spreading of polishing material across the shoe. An optimal friction level is essential; insufficient friction reduces cleaning efficiency, while excessive friction may cause abrasion or material wear. The selection of brush material and regulation of motor speed are therefore crucial in maintaining effective yet safe frictional contact.

5.4. Ergonomics and Biomechanics

Ergonomic and biomechanical considerations form a central aspect of the device design. By allowing shoe polishing in an upright standing or sitting posture, the Automatic Shoe Shiner minimizes forward trunk flexion and knee bending. Such posture optimization significantly reduces mechanical stress on the lumbar spine and lower limb joints. Ergonomic studies have demonstrated that reducing sustained non-neutral postures lowers musculoskeletal strain and discomfort during routine activities [3]. This design illustrates the direct application of biomechanical principles to improve user comfort in everyday tools.

6. Methodology & Experimental Design

The performance and ergonomic effectiveness of the Automatic Shoe Shiner were evaluated using a structured, observation-based experimental methodology. The experimental design focused on analyzing key functional, mechanical, and ergonomic parameters influencing the operation of the device. All experiments were conducted on the fabricated prototype under controlled conditions, following the procedures documented in the author's experimental observation study [2].

6.1. Experimental Approach

An observational experimental approach was adopted to systematically study the behavior of the Automatic Shoe Shiner during operation. This method was selected due to the exploratory and applied nature of the innovation, where real-time performance, user posture, and operational stability were primary evaluation criteria. Each experiment involved varying a single parameter while keeping other conditions constant, allowing clear identification of its influence on device performance and user comfort.

6.2. Experimental Setup

The experimental setup consisted of the fabricated Automatic Shoe Shiner prototype powered by a 9 V DC battery, with dual DC motors driving polishing brushes mounted on either side of the device. The system was operated using a manual ON/OFF switch. Standard footwear was used as the test object, and all trials were conducted in a controlled indoor environment to minimize external disturbances.

The device was tested in both **standing and sitting postures**, ensuring evaluation of ergonomic performance across typical user conditions.

Figure 3: Prototype during experimental evaluation

6.3. Experimental Parameters

Based on the Observation Sheet [2], the following key parameters were investigated:

- **Motor Rotation Direction:** The direction of motor rotation was varied to examine its effect on brushing efficiency and polishing uniformity.
- **Brush Contact Pressure:** The pressure between the rotating brush and the shoe surface was adjusted manually to observe its influence on cleaning effectiveness and surface safety.
- **Battery Power Level:** The effect of battery voltage on motor speed and polishing performance was evaluated to assess operational consistency under varying power conditions.
- **User Posture:** The device was tested in upright standing and sitting positions to evaluate ergonomic comfort and ease of operation.
- **Frame Stability:** Structural stability of the PVC/metal frame was observed during operation to identify vibrations, misalignment, or performance inconsistencies.
- **Shoe Orientation:** The angle and alignment of the shoe relative to the rotating brush were varied to study their effect on polishing uniformity.
- **Switch Responsiveness:** The ON/OFF switch operation was assessed for immediate motor response and user safety.

6.4. Observation and Data Recording

For each experimental condition, observations were recorded qualitatively in terms of polishing effectiveness, smoothness of operation, vibration, user comfort, and ease of control. Expected outcomes were compared with actual observations to assess consistency and identify deviations. This approach enabled practical evaluation of the device's performance without requiring complex instrumentation, aligning with the low-cost and educational objectives of the project.

6.5. Evaluation Criteria

The performance of the Automatic Shoe Shiner was evaluated based on the following criteria:

- Uniformity and effectiveness of shoe polishing
- Operational stability and vibration control
- Ease of handling and user comfort
- Ergonomic improvement compared to manual shoe polishing
- Reliability of electrical and mechanical components

This structured methodology ensured that both functional efficiency and ergonomic benefits of the device were systematically assessed.

7. Result and Observations

The experimental evaluation of the Automatic Shoe Shiner yielded consistent and meaningful results across functional, mechanical, and ergonomic parameters. The observations confirm that the device performs reliably under varying operating conditions while achieving its primary objective of reducing physical strain during shoe polishing. The key findings from the structured experiments are summarized below.

7.1. Effect of Motor Rotation on Polishing Performance

It was observed that controlled motor rotation plays a critical role in polishing effectiveness. Stable rotational motion resulted in uniform brush contact with the shoe surface, producing consistent cleaning and shine. Minor variations in rotation direction did not significantly affect performance; however, smoother rotation was associated with reduced vibration and improved user control. This confirms that appropriate torque and rotational stability are essential for efficient polishing.

7.2. Effect of Brush Contact Pressure

The level of contact pressure between the rotating brush and the shoe surface significantly influenced polishing quality. Light contact pressure resulted in insufficient dust removal, while excessive pressure caused uneven brushing and increased resistance. Optimal contact pressure produced uniform shine without surface damage, indicating that controlled mechanical interaction is crucial for effective friction-based polishing.

7.3. Effect of Battery Power on Motor Performance

Battery power directly affected motor speed and brushing efficiency. With a fully charged 9 V battery, the motors exhibited stable rotation and effective polishing. As battery charge decreased, a gradual reduction in rotational speed was observed, leading to lower polishing efficiency. Despite this, the device continued to operate safely, demonstrating reliable low-voltage performance suitable for household use.

7.4. User Posture and Ergonomic Comfort

One of the most significant observations was the improvement in ergonomic comfort. The device allowed shoe polishing to be performed in upright standing or sitting posture, eliminating the need for forward bending. Compared to conventional manual shoe polishing, users experienced noticeably reduced strain on the back and knees. This observation supports the ergonomic design objective of minimizing non-neutral postures during routine activities.

Figure 4: Comparison of conventional bending posture and upright posture using the Automatic Shoe Shiner

7.5. Frame Stability and Operational Smoothness

The PVC/metal structural frame provided adequate stability during operation. When properly assembled, the device exhibited minimal vibration and maintained consistent brush alignment. Loose or misaligned structural elements resulted in minor vibration, highlighting the importance of proper frame tightening for optimal performance.

7.6. Effect of Shoe Orientation

Polishing effectiveness was highest when the shoe surface was aligned parallel to the rotating brush. Tilting the shoe at an angle resulted in uneven polishing, emphasizing the importance of correct orientation for uniform cleaning. This observation reinforces the need for user guidance during operation.

7.7. Switch Responsiveness and Operational Safety

The ON/OFF switch demonstrated immediate and reliable response during all trials. Motors started and stopped promptly upon activation and deactivation, ensuring user control and operational safety. No unintended motion was observed during handling, confirming the suitability of the control mechanism for safe domestic use.

7.8. Summary of Observations

Overall, the experimental results demonstrate that the Automatic Shoe Shiner achieves effective polishing performance while significantly improving ergonomic comfort. The device operates reliably under low-voltage conditions, maintains mechanical stability, and enables upright posture during use. These findings validate the design objectives outlined earlier and provide a strong foundation for discussion of the device's practical impact and potential improvements.

8. Applications and Societal Impact

Lower back pain and musculoskeletal discomfort are increasingly reported across age groups in India due to lifestyle changes, reduced ergonomic awareness, and repetitive bending during routine daily activities [9]. Such postural stress is not limited to occupational settings but is also common in household tasks, including shoe polishing. Repeated forward bending during these activities contributes to cumulative spinal and knee strain.

The Automatic Shoe Shiner addresses this issue by enabling shoe polishing in an upright standing or sitting posture, thereby reducing forward trunk flexion and associated biomechanical stress. This posture-optimized approach aligns with ergonomic principles that emphasize preventive intervention through task redesign rather than corrective treatment [3], [5], [6]. The low-cost and portable nature of the device makes it particularly suitable for household and community-level use in the Indian context, where access to specialized ergonomic aids remains limited [10].

The device has potential applications among students, officegoers, elderly individuals, and workers involved in small-scale shoe-polishing services. In addition to improving physical comfort, the Automatic Shoe Shiner also promotes awareness of ergonomic practices in daily life. Furthermore, by demonstrating applied physics concepts such as rotational motion, friction, and electromechanical energy conversion, the device contributes to experiential STEM learning and supports the development of scientific temper among students [8].

Overall, the Automatic Shoe Shiner illustrates how simple, affordable ergonomic innovations can address everyday problems while contributing to preventive health awareness and science education in the Indian socio-economic context.

9. Discussion

The experimental evaluation demonstrates that the Automatic Shoe Shiner effectively achieves its intended functional and ergonomic objectives. Stable motor-driven rotation and controlled brush contact resulted in uniform polishing performance, confirming the suitability of simple electromechanical mechanisms for friction-based cleaning applications. The device operated reliably under low-voltage conditions, supporting its use as a safe and portable household system.

A key outcome of the study is the reduction in ergonomic strain achieved through upright operation. By eliminating the need for repeated forward bending, the device addresses known risk factors associated with non-neutral postures and musculoskeletal discomfort, as reported in ergonomic literature [3], [5], [6]. This indicates that redesigning routine tasks using posture-aware solutions can significantly improve user comfort.

The observed influence of parameters such as brush pressure, shoe orientation, and battery power highlights the importance of balanced mechanical design and user interaction. While performance decreased with reduced battery charge, operational safety and stability were maintained, reinforcing the robustness of the design for everyday use.

In comparison with existing studies on human-centered assistive devices, the Automatic Shoe Shiner aligns with findings that emphasize the effectiveness of low-cost, frugal innovations in reducing posture-related strain [4], [7]. Additionally, the device offers educational value by visibly demonstrating applied physics principles, supporting experiential learning approaches in STEM education [8].

Overall, the results suggest that the Automatic Shoe Shiner is a feasible, ergonomically beneficial, and educationally relevant solution for everyday use, with strong potential for further refinement and broader adoption.

10. Future Scope

Future development of the Automatic Shoe Shiner will focus on enhancing technological integration, user convenience, and market readiness. The incorporation of a rechargeable power system and compact motor units can improve energy efficiency and long-term usability. Integrating speed regulation or adaptive brushing mechanisms would allow the device to accommodate different shoe materials and user preferences.

Design optimization aimed at miniaturization, modularity, and durability can facilitate large-scale manufacturing and cost-effective production. The use of standardized components and simplified assembly will support scalability and easier maintenance. Additionally, ergonomic refinements and improved housing design can enhance user experience while maintaining safety and reliability.

With these technological advancements, the Automatic Shoe Shiner has strong potential to evolve into a readily deployable consumer product, suitable for household, institutional, and small-service applications. Such development would enable broader adoption of ergonomic solutions in daily life while promoting accessible and frugal innovation.

11. Conclusion

This paper presented the Automatic Shoe Shiner, a low-cost electromechanical device designed to improve ergonomic comfort during routine shoe polishing. The experimental observations confirmed that the device provides effective polishing while enabling upright standing or sitting operation, thereby reducing bending-related strain on the back and knees.

The integration of simple DC motors controlled rotational motion, and friction-based brushing demonstrates the practical application of fundamental physics and biomechanical principles in everyday tools. In addition to its functional benefits, the device offers educational value by serving as a hands-on model for applied science and engineering concepts.

Overall, the Automatic Shoe Shiner highlights the potential of frugal, ergonomically informed innovation to deliver accessible solutions for daily activities, with scope for further technological refinement and wider adoption.

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