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Design Project of Multi-Functional Military Boots

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Abstract

The effective execution of self-defense functions in military operations relies on the careful development of strategic plans, as well as the use of advanced equipment and support systems that meet current standards. In this regard, military boots play a crucial role. Enhancing military readiness and self-defense requires significant attention to the design of uniforms, particularly boots. Military boots that are currently used in arm forces are functionally limited, serving only to facilitate human movement without providing additional support for operational needs. Soldiers often face challenges such as the inability to charge essential equipment, like flashlights, in the absence of electricity, and the risk of unknowingly entering minefields. This research introduces a conceptual design for military boots that integrates energy harvesting and mine-detection capabilities. Equipped with an advanced sensor system, this footwear can detect and signal the presence of nearby landmines. Additionally, through the integration of specialized transforming components, the shoe can facilitate the safe traversal of mined areas when necessary. This innovative design offers a practical solution to enhance soldier safety and operational efficiency in high-risk environments. It also offers the ability to illuminate the path when necessary. The design is grounded in modern scientific research, studies, and articles published in reputable journals.

Keywords: Boots, Energy Harvesting Technologies, Landmine, Military Footwear.

Introduction

The effective execution of self-defense functions in military operations relies on the careful development of strategic plans, as well as the use of advanced equipment and support systems that meet current standards. In this regard, military uniforms play a crucial role. Each year, scientists strive to enhance their effectiveness by refining materials, design, color schemes, and overall structure. As modern technology advances and military gear evolves, uniforms are continually updated to keep pace with these developments. During military operations, soldiers frequently encounter the hazard of minefields, where the absence of specialized equipment can result in severe casualties. Research by the United Nations estimates that between 15,000 and 20,000 individuals perish annually due to anti-personnel mine explosions. Conflicts, whether wars, armed skirmishes, or border disputes, leave behind thousands of hazardous remnants, continuing to pose lethal risks for decades. Despite being widely condemned as an inhumane method of warfare, anti-personnel mines remain in active use by many states (1). The primary danger of these devices lies in the soldier's constant apprehension of concealed threats. Although international organizations have made significant strides toward demining operations, the issue remains critical due to the limited scope of such efforts, particularly in post-conflict regions and along peaceful interstate borders. An important consideration during military operations is the possibility that soldiers, particularly in unpredictable situations, may find themselves in environments where they require recharging or lighting after extended periods of movement. To address these challenges, a multifunctional military shoe is proposed, capable of serving as a charger by harvesting energy from the soldier's steps.

Historical Background

The design of military boots has undergone significant evolution. The earliest known military boots can be traced back to the ancient Assyrians and Romans. During this period, military footwear was crafted from soft leather, with animal bones used as fastening elements. For instance, the

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Caligae, worn extensively by Roman soldiers, featured an open-toe and open-heel design that facilitated greater mobility in combat. However, this design left the foot vulnerable to injury (2). By the end of the 1st century, the military forces gradually transitioned to the use of closed footwear. The earliest examples of this design, known as "Calceus," were predominantly worn by the Roman upper class. These shoes were constructed from leather and featured a flat sole. Their height extended to below the calf, providing full coverage of the foot and ankle. The fastening system consisted of crisscrossing threads or ribbons. A significant milestone in the evolution of military boots occurred during the 1600s, particularly during the English Civil War, when soldiers would reverse their boots after each battle to ensure even wear. From the 1660s to the 1800s, the incorporation of metal fasteners became a key element in boot design, with widespread application extending to civilian footwear. "Hessian" boots, introduced by the German cavalry in the 18th century, remained in use until the First World War. During World War I, in response to the scarcity of genuine leather, the Soviet Army adopted "kirza" boots, made from a leather substitute (3). During the Second World War, the majority of soldiers from the involved nations, including the Red Army, US Army, and British Army, wore low-laced boots. However, these boots proved inadequate for paratroopers, as they did not provide sufficient protection against foot injuries during parachute landings. To address this, NATO forces gradually adopted high-quality combat boots designed to protect a larger portion of the foot. Specifically, the US Army began replacing the low-cut "M-1943" boots with taller, black leather "Corcoran" boots (3). The Soviet Army, however, continued to use traditional boots, which remained part of the Russian Army's uniform until 2006. Modern summer boots are now made from mesh fabric, offering high abrasion resistance while allowing airflow (4).

Classification of Military Boots

The analytical foundation of this research on military footwear lies in the classification of boots based on their functional significance. Various types of military boots exist, each tailored to specific operational conditions and requirements (5). Furthermore, military boots can exhibit distinct variations based on the environmental and climatic conditions in which they are used. For instance, desert, snow-covered, forest, swamp, mountainous, and plain terrains each demand unique designs and materials. Accordingly, the primary types of military boots will be examined in detail, with an emphasis on their specific features tailored to these diverse conditions (6).

Combat Boots: Combat boots are the most prevalent type of military footwear, designed to offer durability and protection in a range of combat scenarios. Their construction typically includes reinforced toe caps, robust soles, and water-resistant materials to ensure longevity and resilience in harsh conditions (7).

Tactical Boots: Tactical boots share similarities with combat boots but are often lighter and more flexible, allowing for enhanced agility and quick movements (8). These boots are typically constructed from lightweight, breathable materials, feature high collars, and are designed to fit snugly for optimal comfort during dynamic operations.

Military Aviation Boots: Designed specifically for pilots, military aviation boots prioritize comfort and protection during prolonged periods of immobility and varying pressure conditions. These boots are usually made from fire-resistant materials, feature zipper fastenings for quick donning, and have high soles to support extended wear. They are also breathable and lightweight to maximize comfort in the cockpit.

Parade Shoes: Parade shoes are intended for formal military events and are characterized by their polished, sleek appearance. The design emphasizes comfort during long periods of standing, featuring simple yet elegant dimensions and being crafted from highly polished leather.

Training Shoes: Training shoes are utilized during military drills and exercises, designed to endure intense physical activity. Their structure is durable and balanced in weight to support both speed and strength during rigorous training routines.

Trench Boots: Historically, trench boots were indistinguishable from standard combat boots. However, recent advancements have led to the development of specialized "Spider" trench boots, engineered for safe passage through minefields, offering superior protection in such hazardous environments. In summary, while the design of military boots generally follows a standardized approach, specific adaptations are made to accommodate the functional, climatic, and environmental requirements of different military operations (9).

Production Technology of Military Shoes

The manufacturing process of military boots involves a series of intricate steps, from initial design to final production. One critical stage in this process is the assembly of various components, specifically the technique used to fuse the upper part of the boot to the sole. Beginning in the 20th century, the introduction of advanced technologies allowed for the near-total elimination of manual labor, significantly accelerating the production process through the use of specialized machinery. When producing military boots with high durability, specific technologies and guidelines are followed, which directly influence the quality and longevity of the boots? For example, when leather is used, it undergoes treatment with various chemicals and equipment to enhance its strength, elasticity, and to minimize defects. The upper part of the boot is sewn using specialized sewing machines, a complex process that requires precision. Once the upper is complete, it is shaped on molds designed to replicate the human foot (10). After preparing the sole, the final step is to unite the upper and sole into a single product. There are several methods for this: adhesive bonding, stitching, and chemical fusing. In adhesive bonding, the outer sole is attached to the upper part of the shoe using a special adhesive under high pressure and at specific temperatures. This process ensures a tight seal, preventing the penetration of moisture and cold between the bonded parts. The method that combines both gluing and stitching is more durable than adhesive bonding alone. In this technique, the sole is not only glued but also stitched with strong, waterproof threads, enhancing the boot's resilience. After assembly, the boots are treated to achieve the desired shine and smooth surface. This is done by applying oils and greases and polishing the boots using specialized machines. The cold gluing technique is widely used in military boot production. Various types of adhesives, such as neoprene or polyurethane, are employed depending on the design and intended use. For instance, the "Desert Boots" shown below are made using the cold gluing technology mentioned above (11). The renowned "Goodyear" welt construction is used in the design of some of the best shoes in the world. Named after Sir Charles Goodyear, who invented this layered structural system nearly 200 years ago, Goodyear technology remains unique due to its distinctive double-stitching technique. In this method, both the inner and outer edge tapes are double-stitched, securely fastening the upper and sole into a single unit. This robust construction allows the shoes to withstand various impacts and maneuvers. Additionally, a cavity is formed between the midsole and outer sole, enhancing breathability. The Goodyear construction method is prized for its strength, water resistance, and durability across different climatic conditions. However, compared to adhesive bonding techniques, it is more time-consuming due to its complexity. Another widely used method in military boot production is mold compression technology. In this process, the outer and upper soles are bonded using a rubber mold that is formed under high pressure. This method creates strong, durable shoes that are also flexible, allowing them to bend easily without compromising their structural integrity. The mold compression technique is especially suitable for mass production. For harsh climatic conditions, boots with fur linings and high soles made of thermoplastic elastomer or nitrile rubber are more suitable. These materials provide superior insulation and durability. For rock climbing or mountainous terrain, boots with a high base offer better support and stability. If the footwear is intended for long hikes or training, the emphasis should be on lightweight construction to reduce fatigue (12). Leather boots are versatile and can be worn year-round. However, for summer, military boots are often made from lighter materials such as "Cordura" or heavy-duty cotton fabric. "Cordura" is particularly valued for its moisture resistance and low weight. Another popular option is Gore-Tex footwear, which features a membrane that allows the feet to "breathe" while maintaining an optimal internal temperature. As previously mentioned, leather combat boots are suitable for all seasons. However, they can become too hot in warm conditions and, in regions with high rainfall and humidity, leather boots can be difficult to dry. In such environments, Gore-Tex or "Cordura" boots are recommended for their breathability and quicker drying properties. Military boots made with Gore-Tex technology are considered the most comfortable and reliable compared to other options and are now widely used by armed forces in various countries. Despite the growing popularity of high-tech materials, the most common type of military boot remains the long leather version. These boots are typically made from pigskin, prized for its strength, resistance to external impacts, and flexibility, ensuring comfort for the wearer (13). Some designs combine leather and textile materials to allow better air circulation. The soles of military boots are usually made from rubber, though thermoplastic options are also used for their resistance to toxic substances, as well as their ability to withstand extreme temperatures. The upper parts are typically crafted from genuine leather, while the lace hooks are made of metal for durability. In winter versions, the insoles and interior lining are made from lamb fur to provide extra warmth (14). In the Armenian armed forces, the most commonly used boots are long leather versions with laces. However, in recent years, there have been ongoing discussions about updating the overall military uniform to meet NATO standards, including improvements to military footwear. Modern technologies and materials offer a wide range of possibilities for modernizing military boots with entirely new approaches. To explore how the design of military boots can be improved, several studies have been conducted (15).

Ergonomics of Military Boots

In military operations, combat uniforms and boots play a crucial role in ensuring performance across diverse terrains. Soldiers often operate in challenging environments, such as high-altitude zones, deserts, jungles, snow-covered regions, and coastal areas. The application of ergonomic principles in the design of military boots significantly enhances foot protection, reduces the risk of musculoskeletal injuries, optimizes physiological and biomechanical responses, and improves mobility. Extensive ergonomics research has been conducted on the design and development of military footwear in countries like the United States, the United Kingdom, and Australia. During combat, a soldier's mobility can be hampered by various factors, including unpredictable weather conditions such as humidity, extreme temperatures, and the challenging surfaces of different terrains-whether rocky, snowy, desert, or muddy. Ensuring stable mobility and wearer comfort is vital for maintaining the health and combat effectiveness of soldiers (16). Previous studies have highlighted that improper footwear design is a significant factor in lower extremity injuries. Research conducted in the American and British armies in the early 1970s revealed that poorly designed boots were the cause of tendon inflammation, fractures, and blisters in soldiers during training. Subsequent studies suggested that prototype sneakers could serve as a viable alternative to combat boots, as they reduced the incidence of such injuries. However, while sports shoes provide benefits such as shock absorption, flexibility, and supportive heel inserts, they lack the necessary features of military boots, which are designed to offer foot and ankle protection under harsh conditions (17). Laboratory studies comparing various biomechanical properties of five running shoes and combat boots revealed that combat boots were inferior, particularly in terms of flexibility essential quality in combat scenarios. As a result, integrating the flexibility of running shoes into combat boots has become a crucial objective in modern boot design. The characteristics of the terrain play a pivotal role in the design of military footwear. The friction coefficient of different surface types presents a significant challenge to both the physiological and biomechanical demands placed on the wearer and their boots. Terrains such as snow-covered, icy, and sandy areas are particularly difficult for military operations. In addition to the challenging terrain, extreme climatic conditions ranging from +50°C to -50°C, with up to 95% humidity, strong winds, and frostbite risk are common in highlands, deserts, jungles, and coastal environments (18). Inadequate thermal insulation in boots designed for extreme climates can have severe physiological effects. In cold environments, blood circulating from the heart to the feet cools as it reaches the lower extremities, leading to decreased body temperature. Similarly, in hot climates, poor insulation can raise the body’s core temperature, leading to heat-related illnesses (19). Excessive sweating inside non-breathable boots increases friction, leading to blisters and skin maceration. Elevated internal temperatures also cause foot swelling, which can result in compression of nerves and blood vessels, leading to discomfort, reduced circulation, and an increased risk of compartment syndrome. Biomechanically, overheating contributes to the early onset of fatigue, reducing stride efficiency and increasing the metabolic cost of movement. Additionally, excessive moisture buildup inside the boot can alter plantar pressure distribution, increasing the risk of overuse injuries such as plantar fasciitis and metatarsalgia. After identifying several deficiencies in existing military boots such as insufficient thermal insulation, improper sole design, and excessive weight two new boot designs were created, one for regular use and one for winter. These designs were developed based on ergonomic principles, following these key steps:

- Studying the specific environmental and operational needs,
- Conducting a detailed analysis of existing boot designs,
- Proposing a new design concept with improved material characteristics,
- Utilizing an anthropometric database tailored to regional requirements,
- Developing and producing a 3D model of the new design,
- Conducting usability studies on the newly developed boots,
- Implementing necessary modifications based on user feedback.

Energy-saving Shoes

In recent decades, increasing concerns about ecological issues have prompted researchers to explore alternative and renewable energy sources across various fields. Investigating new sources of clean or green energy, such as solar, wind, and hydroelectric power is essential for the development of a modern economy. Among these sources, mechanical movement is one of the most studied types of energy. Mechanical energy, which includes both kinetic and potential energy, can be harnessed from various sources, including industrial machinery, automobiles, human motion, and ocean waves (20). For instance, the mechanical energy generated by walking or running can be harvested through suitable devices integrated into shoes. The most common methods for converting mechanical energy to electrical energy include piezoelectric, electromagnetic, and triboelectric systems, as well as their hybrid derivatives. Each method has its advantages and disadvantages, summarized as follows:

- “Piezoelectric Energy Harvesting”: Ideal for generating and collecting small amounts of energy.
- “Electromagnetic Energy Harvesting”: Capable of providing high power output but requires a larger space for energy generation and collection.
- “Triboelectric Energy Harvesting”: Generally, has low energy capacity due to high internal electrical resistance.

Among the piezoelectric materials used in shoes are lead zirconate titanate (PZT) and polyvinylidene fluoride (PVDF). Both materials exhibit high energy density and capacity, as well as low mechanical damping, making them suitable for efficient energy harvesting applications (21).

The Role of Foot Pressure in the Design of Energy-Storing Footwear

To determine the areas of the foot most exposed to pressure, various studies have been conducted. Medical research on foot pressure highlights not only the causes of various ailments and the significance of foot ergonomics but also helps identify optimal points on the foot for the placement of energy-harvesting sensors through an analysis of foot morphology. Such studies provide insights into the best locations for the necessary equipment, as well as design conditions and limitations, both in static positions and during movement. Different types of force transducer cells such as force sensors, piezoelectric elements, and strain gauges are incorporated into force plates and insole devices to measure pressure underfoot (22). For this type of study, a specialized method has been developed that divides the foot into conventional sections, allowing for the distribution of pressure across these areas to be analyzed. These pressure distributions can vary due to several factors, including age, body mass, and the type of footwear worn. During walking, the kinetic energy generated under the foot is transferred to the midsole, which consists of a layer of elastic material positioned between the foot and the ground. This energy is partially stored as elastic strain energy, which is then returned to the leg and dissipated as heat within the midsole. The magnitude and direction of the load applied to the foot during walking play crucial roles in controlling movement and maintaining balance. Vertical ground reaction forces can exceed horizontal forces by a factor of five or more, and they surpass lateral forces by even greater margins, making vertical forces the primary source of kinetic energy obtained from human steps (23). To understand the parameters of foot pressure, an experiment was conducted in which the results were measured during the running of 20 adult men. The force generated by heel strikes during walking and running creates significant mechanical energy in the heel area, which is typically absorbed by the heel pad and surrounding tissues. The amount of mechanical energy that the heel pad must absorb during impact loading while walking and running varies from 0.24 to 3.99 J before each impact (24). A rough calculation indicates that the vertical ground reaction can generate a maximum power of 2 W under the foot, assuming it is 1.2 times the body weight of an 80 kg individual and there is a vertical displacement of 4 mm in the sole. The piezoelectric energy conversion efficiency of the shoe, which transforms mechanical energy into electrical energy, is estimated at 4.7%. Underfoot acceleration is primarily generated by heel strikes and foot swings, serving as the main driving force for energy harvesting devices, such as cantilever piezoelectric energy harvesters. The changes in force due to acceleration during walking are illustrated below (25).

Construction of Shoes with Piezoelectric Energy Absorbers

These shoes are specifically designed to absorb foot pressure and counteract the forces exerted by the ground. The piezoelectric energy absorbers in the soles are constructed from materials that maintain their shape and contribute to minimizing fatigue while enhancing foot comfort due to their softness. To improve power generation efficiency, piezoelectric transducers with specialized amplifiers are utilized to increase the feedback force from the ground (26). Piezoelectric absorbers are primarily located in the heel area, although they are sometimes also positioned in the lower part of the foot. The flat plate energy absorber features a straightforward structure, consisting of thin piezoceramic disks or foils that are coated with metal electrodes on both sides. These absorbers are typically thin and flexible, and they are usually attached to or integrated into shoe inserts. Additionally, they must be well-protected from direct contact with the foot, as well as moisture and dirt (27). A hexagonal piezoelectric energy absorber is positioned beneath the sole of the shoe. This absorber features a 2 mm flexible plastic substrate with epoxy-bonded foil layers on both the top and bottom. The layers are connected in parallel to reduce resistance and facilitate current flow. Compared to flat plate absorbers, curved structures are generally more efficient because they can generate higher strain and store more mechanical energy in the piezoelectric materials through the application of arc forces. Such an absorber consists of curved, thin, flexible piezoelectric films, including monomorphic composite layers and foils. These plates are affixed to a rigid metal or plastic base. When the driving force is removed, the deformed piezoelectric layer returns to its original shape. As the curved energy harvester is compressed, the piezoelectric plates on the top surface of the core base contract, while those beneath the substrate expand. The tensile and compressive strength of the piezoelectric films is enhanced by the curved structure, allowing for greater energy capacity. The exploration of the aforementioned options demonstrates that utilizing energy accumulation through human steps is currently quite optimal. There are already shoes available that harness this energy storage capability to function as chargers for mobile phones. As previously mentioned, soldiers may sometimes find themselves in situations where they lack the ability to charge flashlights or other equipment. In such cases, integrating innovative technology into the design of military boots can provide significant assistance. When discussing the modernization of the military sector through innovative technologies, it is essential to highlight the advancements in anti-mine footwear. Currently, the primary structural difference in the design of boots intended for movement in minefields lies in the sole area. Below, we will discuss several types of such shoes.

Types of Anti-Personnel Mines and Anti-Resistant Footwear

Before discussing anti-mine boots, it is essential to distinguish the main types of anti-personnel mines. These mines are typically classified into three categories: high-explosive, fragmentation, and bullet mines.

High-Explosive Mines: High-explosive anti-personnel mines detonate when direct pressure is applied to their surface. In most cases, the soldier's foot that triggers the mine is severely damaged, while the other foot may remain unharmed depending on the distance from the explosion.

Fragmentation Mines: The anti-personnel fragmentation mine (e.g., HBA-2M) is encased in cast iron and contains an explosive charge, a detonator, and a triggering mechanism. This type of mine has a circular effective radius of up to 4 meters and is loaded with thousands of cylindrical fragments. When detonated, it explodes at a height of 0.6–0.9 meters above the ground. The mine's design allows it to be used with various detonators, including remote-controlled options. Fragmentation mines can be categorized into directional and omnidirectional types based on their blast pattern.

Bullet Mines: Bullet mines function by launching a 7.62 mm TT bullet that punctures the foot upon detonation. These mines are usually concealed under a thin layer of soil, typically 1–2 cm deep (28). One option with a high rubber sole is the "ZEMAN AM-35" model, which offers several notable features. The upper is constructed from matte, hydrophobic leather with a thickness of 2.2–2.4 mm and includes a closed tongue for added protection. The interior is lined with fabric, and the insole is designed for ergonomic comfort, allowing for replacement during extended use. The sole is crafted from rubber and reinforced with a "smart" metal frame. For size 46, the shoe weighs no more than 3100 grams per pair. The unique structure of the sole provides full protection for the leg during a mine explosion, with only the lower part of the sole being damaged. Another model of anti-mine footwear is the "PPE100," which shares a similar structure to the "ZEMAN AM-35" but incorporates more advanced design solutions. The multi-layer composite structure, utilizing SabreMat® technology, significantly reduces the risk of leg injury from shrapnel during an explosion. A redesigned lacing system allows for quick removal of the shoe in the event of injury. The interior is lined with breathable fabric to enhance foot comfort. Each shoe weighs approximately 2.3 kg. The lower part of the sole is engineered to absorb and disperse the energy from an explosion, ensuring that the upper part remains intact. The shoe is made from breathable materials that are both waterproof and heat-resistant. Another option is the "Wellco Blast Anti-Mine Overboot," which features a slightly different design. These boots are specifically engineered for use in muddy, sandy, or rocky terrain while ensuring foot protection during a mine explosion. The sole has a unique structure that redirects the force of the explosion laterally, protecting the foot. Inside the polyurethane sole is a layer of stainless steel and aluminum, which absorbs the explosion's energy. Additionally, the insole is made of multi-layered Kevlar for enhanced protection. The latest innovative anti-mine solution is the "Spider Boot," an additional sole attachment developed by Canadian scientists. These soles can be fastened to any combat boots, allowing safe passage through minefields. The design is based on a weight-balancing system that distributes the wearer's weight across four legs, redirecting the force of an explosion laterally, thereby reducing the risk of leg injury. The "Spider Boot" is constructed from composite materials, including plastic and rubber, and is currently being used by the Ukrainian armed forces in their conflict with the Russian Federation. Mine-covered areas remain highly dangerous even after the end of hostilities, as many hidden mines stay in place, posing long-term risks. Therefore, mine detection is a crucial task. During military operations, soldiers may unintentionally find themselves in minefields. To navigate such areas, specialized footwear with ultra-sensitive detection systems has been developed (29). One such conceptual innovation is the "SaveOneLife" in-shoe anti-mine alarm system, designed by Bogotá-based Lemur Design Studio. This system uses a coil of wire that emits an electromagnetic field, detecting nearby metal objects, including mines. The system is connected to a wristwatch, which alerts the wearer to change direction in case of danger. Another example of an anti-mine signal shoe design was developed not only for military use but also for civilians working in border areas. Unfortunately, there have been many instances where civilians, particularly those involved in agriculture, have encountered mines in fields, often with tragic consequences. This design, similar to the previous example, includes a coil of wire that detects nearby metal objects, accompanied by a sound and light alarm system. These components are embedded within the sole of the shoe and alert the wearer through light and sound signals when danger is detected.

Material and Methods

Comparative studies on the subject are conducted using both local and international prototypes. The theoretical foundation of the research is based on articles published in internationally recognized journals, focusing on the latest technological advancements and modern scientific breakthroughs. Experimental research is performed and generated by three-dimensional programs. The results will be presented through computer software, utilizing advanced image processing techniques, detailed drawings, and three-dimensional animation analysis to accurately illustrate the project.

During the execution of the project, the following tasks were undertaken:

- Conducting a scientific investigation into the historical evolution of ergonomic characteristics in military boot prototypes,
- Administering surveys,
- Analyzing contemporary anti-mine technologies,
- Investigating prototypes of self-charging batteries and charging systems,
- Creating conceptual design sketches based on research findings,
- Developing anatomical symmetries, structural components, material usage, and assessing the technical feasibility of the project,
- Advancing the project through computer-aided design (CAD) software.

Results and Discussion

The comfort and ergonomic design of military boots are of paramount importance. To achieve optimal ergonomics in footwear design, comprehensive studies are conducted, following a series of specific stages. The first step involves assessing foot symmetry, which is performed using advanced scanning devices. This data is then used to create a three-dimensional model of the foot. The entire design of the boot is based on this 3D model to ensure a precise fit and enhanced comfort. Anthropometric data of the foot plays a crucial role in shoe design. Typically, these measurements are taken with the right foot as the base, ensuring that the distance between the two feet is maintained at 20 cm and that the body weight is evenly distributed (30). The conducted study demonstrates that advancements in science and technology provide extensive opportunities for improving the military industry. Consequently, numerous innovative ideas are being developed to enhance combat capabilities through military equipment. The research findings have laid the foundation for the conceptual design of a mine-resistant, multi-functional military shoe. To enhance military preparedness and improve self-defense capabilities, a conceptual proposal for anti-mine, multi-functional military shoes has been developed. This design aims to reduce the number of human casualties in military situations.

Features of Anti-Mine, Multi-Functional Military Shoes:

- Innovative design for quick and easy donning and doffing.
- Piezoelectric charger integrated into the sole.
- Built-in charging system.
- Built-in flashlight.
- Integrated anti-mine alarm system.
- Additional mounting components for safe movement in minefields.

The design of these anti-mine, multi-functional military shoes incorporates modern materials and principles found in The North Atlantic Treaty Organization (NATO) military footwear, along with the latest technological advancements. NATO military boots are designed for durability, protection, and performance across various environments. Alternative materials used in their construction can include full-grain leather, suede leather & nubuck, Cordura nylon, Kevlar, or ballistic nylon. Comparative examination reveals that all the materials mentioned above are highly durable, water-resistant, and breathable. The design is grounded in accepted ergonomic measurements and standards.

Based on the collected data, sketching was undertaken, which included:

- Developing the sole using ergonomic foot proportions.
- Designing an innovative fastening system for ease of wear.
- Sketching the foundational structure.
- Shaping the upper portion of the shoe.
- Developing attachable anti-mine components.

Some of the sketches mentioned above are introduced in Figure 1. As a result of the sketching process, various form creation options were proposed, and the main volumes were clarified. These elements served as the foundation for three-dimensional modeling using appropriate software. At this stage, the primary dimensions of the sole, upper, and fastening joints were developed and are presented in Figure 2.

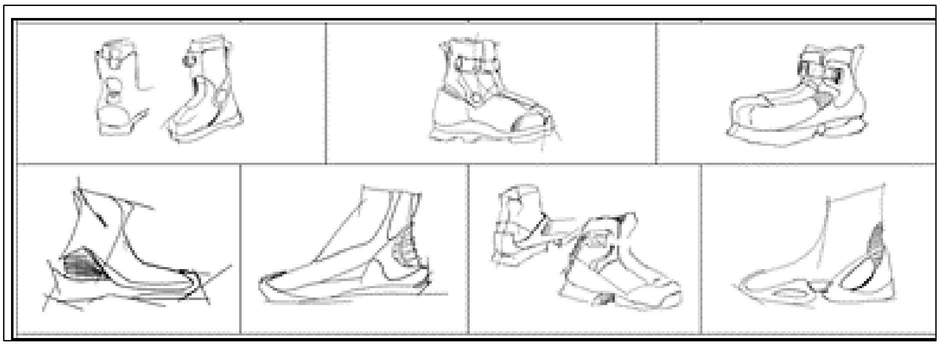

Figure 1: Military Boot Sketches

Figure 2: Military Boot Sketches

The integration of advanced technologies in multi-functional military boots inevitably presents trade-offs between enhanced functionality and practical usability. The design of the sole in the anti-mine military boot is based on the fundamental structure of NATO boots to maintain familiar ergonomics and ease of use. However, incorporating sensitive anti-mine sensors and a piezoelectric energy harvester in the heel area introduces additional design complexities. The primary challenge is the potential increase in weight due to embedded components. While the piezoelectric energy harvester accumulates electricity during movement, functioning as a power source for a front-installed flashlight and a mine-warning light, the added electronic elements require careful material selection to prevent excessive burden on the user. Weight optimization strategies, such as lightweight composite materials and miniaturized circuitry, are being considered to ensure that these enhancements do not impede soldier mobility. Additionally, the integration of interconnected internal components raises concerns about durability and environmental resistance. Military boots are subjected to extreme conditions, including water exposure, high-impact forces, and temperature variations. Ensuring the long-term reliability of the embedded technology without compromising the structural integrity of the boot requires further real-world testing. While computer-based simulations have validated the feasibility of these features, the next phase involves producing physical prototypes to conduct extended durability testing in operational environments. Another key aspect is power management and efficiency. The self-sustaining power system reduces dependence on external charging sources, which is advantageous in combat scenarios. However, optimizing the energy output of the piezoelectric harvester to sufficiently power all integrated features without excessive foot fatigue remains a critical focus of future design refinements. Despite these challenges, the life-saving potential and operational benefits of this innovation justify the investment in further research and development. The ability to detect landmines while maintaining normal movement, combined with self-sustaining power generation, enhances both soldier safety and mission effectiveness, making the trade-offs a worthwhile consideration. The exploded view of the military boot is presented in Figure 3.

Figure 3: Exploded View of Military Boot

These components are lightweight and compact, ensuring they do not add significant weight to the military shoes or impede movement. Additionally, the introduction of an opening in the middle of the boot is a novel feature that facilitates easy and quick donning and doffing. This design element was originally developed by the world-renowned sports brand Nike to enable basketball players to easily remove their shoes. Subsequently, Nike created the "FlyEase" models, which allow individuals with disabilities to put on and take off shoes effortlessly. This feature of the shoe significantly accelerates the process of putting it on and taking it off, providing a substantial advantage for military personnel. The design of the military shoe employs a unique approach, wherein the shoe is vertically divided into two sections: the front and the back, which are secured at the top with a simple knot. It is shown in Figure 4.

Figure 4: The Closed and Open Views of the Military Boot

The sole consists of two layers: the first layer extends the full length of the foot, while the second layer covers only half. These layers are connected through a specially developed joint and a rubber layer. This construction eliminates the need for long strap ties or metal chains, as the shoe "splits," creating a wide opening for easy foot entry. Once the foot is inserted, the shoe closes automatically, requiring only a knot at the upper part for secure fastening. Comfort for various foot sizes is ensured by a rubber elastic layer that replaces the traditional tongue, attaching to the front part of the shoe. The integration of advanced materials, embedded sensor technology, and self-sustaining power systems in the designed military boots significantly enhances their applicability in modern military operations. One of the primary innovations in these boots is their anti-mine protection capability. The incorporation of highly sensitive anti-mine sensors enables real-time detection of explosive threats, thereby reducing the risk of casualties among military personnel. This function is particularly critical for infantry units deployed in mine-infested zones, peacekeeping forces working in post-conflict regions, and humanitarian demining missions. The interconnected warning system, which includes a flashlight linked to the mine-detection mechanism, ensures immediate visual alerts, facilitating rapid decision-making in high-risk areas. In addition to their protective features, the boots contribute to enhanced tactical mobility and operational efficiency through the integration of a piezoelectric energy harvester. It is particularly advantageous for special forces units, reconnaissance teams, and long-range patrols, where continuous access to power is a logistical challenge. Moreover, reducing the need for additional battery packs minimizes the overall load carried by soldiers, improving mobility and decreasing fatigue. The design also incorporates advanced temperature-regulating materials, ensuring adaptability to extreme climatic conditions. In cold environments, insulating layers prevent heat loss, thereby reducing the risk of frostbite and maintaining foot dexterity. Conversely, in hot climates, breathable materials facilitate heat dissipation and moisture management, preventing excessive sweating and thermal discomfort. This dual adaptability renders the boots highly effective for military operations in arctic, desert, and tropical warfare conditions, where temperature fluctuations can significantly impact soldier performance and endurance. Existing high-performance military boots prioritize durability, water resistance, and traction but lack integrated technologies for adaptive response and energy autonomy. In contrast, the proposed design incorporates anti-mine sensors, a piezoelectric energy harvester, and climate-adaptive materials, enhancing soldier safety and efficiency. Unlike conventional boots, which rely on static features, the new design offers real-time hazard detection and self-sustaining power generation, reducing logistical dependencies in the field. Although the large-scale production of these military boots is achievable, it presents greater complexity and higher costs compared to conventional manufacturing due to the incorporation of advanced technological innovations. However, these enhancements are justified by the significant benefits they offer in terms of soldier safety and operational efficiency, making them a worthwhile investment for military applications.

Conclusion

The conclusion of the research is the new design proposal for military boots. The sole of the designed boots incorporates a piezoelectric energy harvesting system, which captures mechanical energy from each step and stores it for later use. A USB charging port located on the side of the shoe enables access to the stored energy, allowing it to serve as a mobile power source when required. In addition, the stored energy can power an integrated lighting system at the front of the shoe. This feature provides illumination for the soldier's immediate surroundings in low-visibility conditions, aiding navigation and safety. Moreover, the shoe contains an anti-mine sensor embedded within the sole. This sensor is sensitive to metallic objects, enabling it to detect the presence of landmines or other metal-based hazards in the vicinity. When such a threat is detected, the sensor triggers a visual alert, warning the wearer. In scenarios where soldiers must navigate through minefields, an additional attachment is included with the shoe: a four-legged transformable sole. This attachment is designed to be adjustable based on the wearer's foot size and enhances safety by distributing the weight evenly across its four legs. By raising the foot to an optimal height and dispersing gravitational forces, this attachment minimizes the risk of severe injury, even in the event of a mine explosion. Surveys indicated that prolonged wear of the shoes often resulted in discomfort, particularly in the heel area. To address this issue, a layer with a rubber structure was introduced in this part, providing additional elasticity and softness to prevent foot pain. Overall, the conclusion can be drawn that the innovative design of military boots can strengthen the efficiency of arm forces for many times.

Abbreviation

NATO: The North Atlantic Treaty Organization

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Author Contributions

All authors contributed equally.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

Not applicable.

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