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# Development of a Shoe Sole Disinfection Machine for Office and Hospital Use

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**ABSTRACT**

The pervasive role of footwear as a vector for pathogenic microorganisms necessitates effective disinfection solutions, particularly in hygiene-sensitive environments like hospitals and offices. This study presents the design, fabrication, and performance evaluation of an automated shoe sole disinfecting machine that integrates mechanical brushing with ultraviolet –C (UV-C) light sterilization. The system employs a chain-driven dual-brush mechanism powered by a 24V DC motor, complemented by 254 nm UV-C lamps for microbial inactivation. Activation is automated via a limit switch, ensuring touch-free operation. Performance testing using dry and wet mud samples demonstrated high cleaning efficiency, with dry mud removal rates of 95-99% within 4-7 seconds and wet mud removal rates of 88-92% within 8-11 seconds. The results validate the machine as a rapid, efficient, and eco-friendly alternative to conventional chemical- based methods, offering a practical solution for reducing cross- contamination via footwear in public and clinical settings it is recommended that future work focus on quantitative microbiological testing.

## 1. INTRODUCTION

The COVID 19 pandemic has heightened global awareness of infection prevention and control, shifting focus to all potential transmission pathways - including frequently overlooked surfaces such as footwear. Shoes and floors can act as reservoirs and vectors for pathogens. Studies have shown that shoe soles in healthcare settings frequently carry organisms such as methicillin resistant Staphylococcus aureus (MRSA), vancomycin resistant enterococci (VRE), and Clostridioides difficile, contributing to cross-contamination and healthcare-associated infections (Rashid et al., 2016; Armellino et al., 2019; Torres Teran et al., 2023). Conventional footwear hygiene methods, such as disinfectant-soaked mats or manual scrubbing, have limitations: they are labour-intensive, require consistent monitoring, and are often impractical in high-traffic areas (Rutala and Weber, 2008; Samal et al., 2020).

Walking on contaminated floors can re-suspend pathogens into the air, increasing the risk of aerosol transmission (Neely et al., 2023). Consequently, automated or rapid disinfection systems are necessary to reduce microbial spread from footwear and floors. Evidence indicates that an 8-second UVC treatment of shoes significantly reduces the transfer of vegetative bacterial pathogens from healthcare personnel footwear into patient rooms (Torres Teran et al., 2023). In addition, far UVC wall-mounted devices have been shown to reduce microbial contamination on surfaces and in aerosols in hospital bathrooms, including MRSA, VRE, Candida auris, and bacteriophage MS2 (Kaple et al., 2024).

Hybrid disinfection methods have also been explored: combining UVC radiation with chemical or gaseous agents has shown significant reductions of bacteria, spores, and fungal biofilms on various surfaces (Różańska et al., 2023; Górny et al., 2024). Environmental sources of fungal infections, such as contaminated shoes, socks, and foot-care instruments, also contribute to recurrent infections and antifungal resistance (Gupta et al., 2025).

In addition, UVC LED systems (279 nm) have demonstrated effective inactivation of surface-deposited bioaerosols of pathogens including Escherichia coli, Salmonella Enteritidis, and Pseudomonas fragi on food contact surfaces (Sharma et al., 2024). Furthermore, photo catalytic coatings in sports environments have been shown to reduce bacterial and fungal contamination sustainably, offering an eco-friendly alternative to conventional chemical disinfectants (Ubaldi, 2025).

Given this evidence that shoe soles and floors are important vectors, that walking can resuspend pathogens, and that both UVC, hybrid automated disinfection systems, and photocatalytic methods show promise - there is strong justification for developing an integrated shoe sole disinfection machine. Such a device would combine mechanical debris removal with microbial decontamination via UVC or other safe methods, providing a cost- effective, efficient, and environmentally friendly solution suitable for hospitals, offices, and other high-traffic areas.
The following computations were used in the study;

$$Torque, T = Force \times Radius \tag{1}$$

$$Power, P = 2NT \tag{2}$$

Where N = Number of Revolution, and T = Time

Torques transmitted in the sprocket and Chain

$$T = (T_1 - T_2) \times r \tag{3}$$

Where $T_1$ and $T_2$ are the tight and slack side of the chain, r = pitch radius

Power transmitted in the sprocket

$$P = (T_1 - T_2) \times V \tag{4}$$

Where V= speed

Maximum Bending moment

$$M_{max} = \frac{FL^3}{48EI} \tag{5}$$

Where;
F= load,
L= Length,
E= Young modulus,
I= moment of Inertia

## 1.2 Related Work done

The pursuit of effective footwear disinfection has led to the exploration of various mechanical and non-chemical methods. Chen et al. (2019) developed a system using rotary brushes combined with a disinfectant spray, demonstrating the efficacy of mechanical action for dirt removal but highlighting a continued dependency on liquid chemicals. This underscores a critical area for improvement: achieving disinfection without chemical residues. Concurrently, Ultraviolet-C (UV-C) radiation has emerged as a potent sterilization technology. Operating at a germicidal wavelength of 254 nm, UV-C light inactivates microorganisms by disrupting their DNA and RNA, preventing replication (Kowalski, 2009). Its effectiveness against a broad spectrum of bacteria and viruses on various surfaces has been well-documented (Liu et al., 2011; Zhang et al., 2020), making it an ideal, chemical-free complement to mechanical cleaning. Recent trends in hygiene technology emphasize automation and user safety. The integration of infrared or proximity sensors enables touch- free activation, reducing the risk of cross-contamination and enhancing user compliance (Ajees et al., 2023). Such automated systems are becoming a cornerstone of modern hygiene infrastructure.

Furthermore, there is a growing recognition of the importance of locally fabricated solutions, particularly in developing regions. Utilizing indigenous materials and design approaches promotes affordability, ease of maintenance, and technological self-reliance, ensuring the sustainability and long-term adoption of such innovations (Chen et al., 2019). Despite these advancements, a review of existing literature reveals a scarcity of integrated systems that seamlessly combine robust mechanical brushing with UV-C sterilization specifically for footwear. This study aims to fill this void by designing and fabricating a hybrid system that offers a two-stage decontamination process, thereby potentially achieving a higher overall level of cleanliness and pathogen control. (Rashid et al., 20216).

## 2. MATERIALS AND METHODS

### 2.1 Materials

### 2.1.1 System Design and Components

The shoe sole disinfecting machine was designed with a focus on functionality, durability, and local manufacturability. The core structure consists of a rigid steel frame housing the following key components:

### 2.2.1 Method

The shoe sole disinfecting machine was designed with a focus on functionality, durability, and local manufacturability. The core structure consists of a rigid steel frame housing the key components: a 24V DC micro motor for motive power, a chain-and-sprocket transmission system to drive parallel nylon brush rollers, UV-C lamps for sterilization, and a control system with a limit switch for automated, touch-free activation.

**Table 1:** Components, Functions and Durability

| Component | Function in Shoe Sole Disinfecting Machine | Durability | Local Manufacturability |
|---|---|---|---|
| **Nylon Brush** | Scrubs the underside of the shoe to remove dirt before UV disinfection. | Resistant to wear and moisture; holds up well under repeated scrubbing. | Easily sourced from local brush makers; can be fabricated locally. |
| **DC Motor** | Drives the rotation of the brush and moving parts. | Durable if properly cooled and protected from moisture. | Readily available in local electronics markets; repairable locally. |
| **Ball Bearing** | Allows smooth rotation of the shaft that carries the brush. | Very durable with lubrication; handles continuous rotational load. | Available locally; although imported, easy to replace and machine shops can fit them. |
| **Chain and Sprocket** | Transfers power from the DC motor to the brush shaft for synchronized brushing. | High durability, especially for continuous mechanical motion. | Can be fabricated by local metal workshops or purchased in local mechanical markets. |
| **Shaft** | Holds the brush and rotates it for cleaning the shoe sole. | Very strong and long-lasting when made from steel. | Can be produced in local machine shops using lathe machines. |
| **Control Panel** | Contains the system controls (power switch, motor control, UV activation) for user operation. | Durable with protective casing; metal enclosures last longer. | Can be assembled locally using available components such as switches, wires, and relays. |
| **UV Light** | Sterilizes the sole of the shoe by killing pathogens after the brushing stage. | Effective but fragile; must be shielded from direct impact. | Usually imported but widely available in local electronics markets. |
| **Battery** | Powers the motor, UV light, and control panel for portable operation. | Long-lasting with proper charging; lifespan reduces with deep discharge. | Locally available, though manufactured abroad. |
| **Switch** | Turns the machine or specific functions ON/OFF (e.g., brush, UV). | High durability when protected from dust and moisture. | Easily sourced in local electrical markets; supported by local technicians. |

A 24V DC battery provided backup power. Rigorous engineering calculations were performed to ensure structural integrity. Motor torque and power requirements were calculated based on a 50 kg load. The chain drive system was analyzed for tension and power transmission capacity, and the central shaft was designed to withstand bending and torsional stresses, leading to the selection of a 25 mm-diameter mild steel shaft.

**Fig 1:** *Wielding of the sprocket*

**Fig 2:** *Testing of dry and wet mud removal*

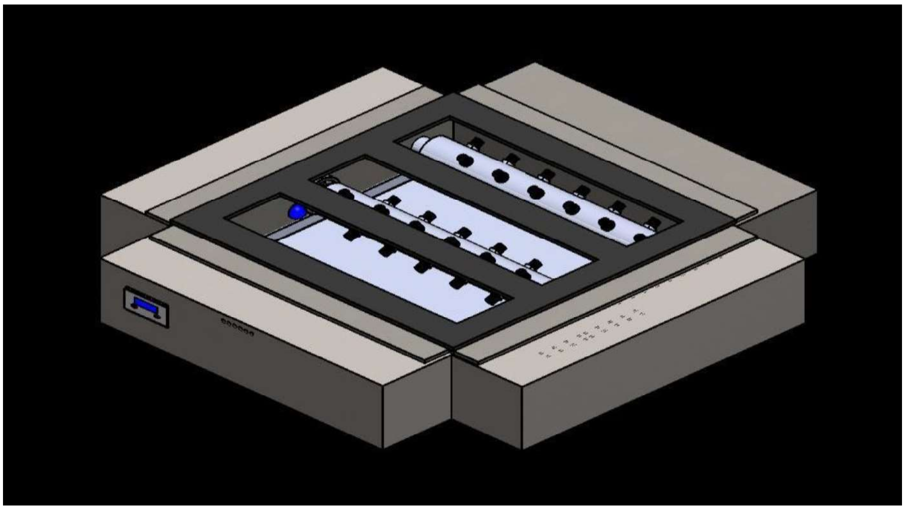
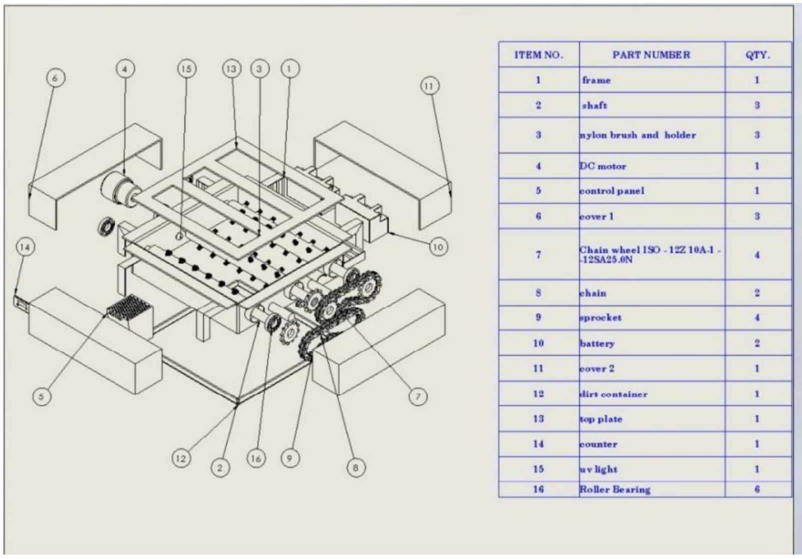


**Fig 3:** *Engineering drawing showing the frame and the roller brushes*



| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | frame | 1 |
| 2 | shaft | 3 |
| 3 | nylon brush and holder | 3 |
| 4 | DC motor | 1 |
| 5 | control panel | 1 |
| 6 | cover 1 | 3 |
| 7 | Chain wheel ISO - 12Z 10A-1 -<br>-12SA25.0N | 4 |
| 8 | chain | 2 |
| 9 | sprocket | 4 |
| 10 | battery | 2 |
| 11 | cover 2 | 1 |
| 12 | dirt container | 1 |
| 13 | top plate | 1 |
| 14 | counter | 1 |
| 15 | uv light | 1 |
| 16 | Roller Bearing | 6 |

***Fig 4:*** *An Engineering drawing that shows all the components of the machine*

Bearings were selected based on a calculated dynamic load requirement for a 5-year lifespan, a deep groove ball bearing with a significant safety margin. The machine's performance was evaluated by testing its efficiency in removing dry and wet mud samples from standard shoe soles, recording both the percentage of mud removed and the cleaning time for six samples in each condition.

## 2.2 Design Analysis and Calculations

### i. Design Calculation for Electric Motor

From Equ. 1, We need to Calculate the force

$$Force = \text{Self load} + \text{Foot Load} \times g = m \times g \quad (6)$$

$$= 50kg \times 9.81 = 490.5\ N$$

Given, $Radus = 110mm$

Torque, T = 490.5 × 110 = 53955 Nmm

From Equ. (2), $Power, P = 2NT = 60 \times 10^3$

$N = 2400rpm\ (Micro\ DC\ Motor)$

$= 13562.1288\ kW$

Shaft torque capacity

Torsion formula (Obtaining maximum shear, $T_{max}$)

Remaining:

$T(allowable) = 48.083 \times 10^6$ Pa

D = 0.025m

T = 147.52N.m

Tension difference relating to torque

$$T_1 - T_2 = 537.77\text{N} \quad (7)$$

Chain tight- Slack tension difference = 537.77 N

Tension ratio from friction wrap model using Euler type relation for chain/sprocket

Given, K = 0.25

= 2.19328

$\Rightarrow T_1 = KT^2$

$T_2$ = 450.67N

$T_1$ = 2.19328 x 450.67 = 988.45N

Chain linear speed: D= sprocket diameter

V = 68.944m/s

Power transmitted (from and V)

$$P = (T_1 - T_2)V = 537.77 \times 68.944 \tag{8}$$

= 37076.015 W

=37.08 kW = 37.1 kW

Design calculation for shaft: 490.5 N

Material for shaft is mild steel

Where y is between 235Mpa – 250Mpa

Taking average to get the y at the centre of the shaft, where the stress is highest,

Stress = 125MPa

Using factor of safety, FOS = 3 Allowable shear stress

Ss = 41.67MPa

Torque transmitted by the sprocket /chain drive system

$$M_t = (T_1 - T_2)R \tag{9}$$

Where;

$M_t$ = torque transmitted in (N.m )

$T_1$= tension in the tight side of chain N= 988.45 N

$T_2$= tension in the slack side of chain (in N) =450.67 N R= Radius of the sprocket =55mm

R = 27.5mm

Mt = (988.45 − 450.67) x 27.5 = 537.78 x 27.5 = 14788.95 Nmm

Vertical reaction 490.5N

For a simply supported beam with a central vertical load F, the reaction at each support is:

$\Sigma fy=0$

$$R_A + R_B - F = 0 \tag{10}$$

$$R_A = R_B$$

So, $R_A = R_B$ = 245.25N (upwards)

Horizontal reactions = 0N

Shear force to the left side of the load

$$V_{Left} = +R_A = +245.25\text{N} \tag{11}$$

Shear force to the right side of the load

$$V_{Right} = -R_B = -245.25\text{N} \tag{12}$$

Central downward point load, F= 490.5N Diameter, D = 30mm

Span, Length L = 400mm

Young's modules, E =210 kN/mm$^2$

= 210,000N/mm$^2$

= 210GPa

Since it is a solid circular shaft moment of inertia,

I = 39760.782
= 3.97608x104mm$^4$
$M_{max}$ = 49050, C = 15mm
Max bending $M_{max}$, = 49050 x 15
= 18.50N/mm$^2$
= 18.50MPa
$I.$ = 39760.782
Maximum downward deflection (at midspan)

$$M_{max} = \frac{FL^3}{48EI} \tag{13}$$

= 490.5x4003 / (48 x 210000 x 39760.782)
= 0.0783mm
Shaft diameter: using $d_3$ = 16 max
max = + ($K_t$ x $M_t$)$^2$ (14)
For rotating shafts when load is suddenly applied (minor shocks) $K_b$ = 2.0 and $K_t$ = 1.5
$M_B$ = 49050Nmm
$M_t$ = 14788.95 Nmm
max = + (1.5x14788.95)$^2$
= + 492104344.73 = 100576.908Nmm
$d_3$ = 23.08mm 23mm
Therefore, a shaft of diameter 25mm is suitable and protecting. Shaft diameter for bearing is 25mm.
Type of bearing =single row deep groove ball bearing tension on chain/ sprocket system
$T_1$ = 988.45N; $T_2$ = 450.67N
$T_1$ + $T_2$ = 1439.12N
N = 2400rpm
Machine continuous operation (4 -8hrs per day) on the bearings: 5 years Radial load, P = 490.5N
C = Target life,
L10h = 5x365x24hours (15)
= 43,800hrs
n = 2400rpm
C = 490.5 x154751
= 9062.6N
C = 9.06 kN at the same load and speed.
Comparing the value of C = 9.06kN to the bearing capacity used, SKF 6305 -2 RS1/C3, where C = 23.4kN, the margin =2.58.
The bearing capacity is more than adequate.

## 3. RESULTS AND DISCUSSION

### 3.1 Dry Mud Removal and Cleaning Result

The performance evaluation (Table 1) of the fabricated shoe sole disinfecting machine produced significant results that validate its design objectives. Beginning with dry mud removal, the data demonstrates exceptional efficiency, with rates ranging from 95% to 99%.

**Table 2:** Dry Mud Removal and Cleaning Time

| Test Sample | Initial Mud Cover page (%) | Dry Mud Removal (%) | Cleaning Times (Seconds) |
|---|---|---|---|
| 1 | 100 | 98 | 5 |
| 2 | 100 | 96 | 6 |
| 3 | 100 | 97 | 5 |
| 4 | 100 | 95 | 7 |
| 5 | 100 | 99 | 4 |
| 6 | 100 | 97 | 6 |

Table 2 shows that with initial mud coverage of 100% across all samples, the machine achieved high dry mud removal efficiencies between 95% and 99%. Cleaning times ranged from 4 to 7 seconds, with most samples requiring about 5–6 seconds. These results indicate consistent and efficient performance under dry mud conditions, demonstrating the effectiveness of the brushing mechanism in achieving near-complete cleaning within a short time.

Wet Mud Removal and Cleaning Result

### 3.2 Wet Mud Removal and Cleaning Time

The results for wet mud removal (Table 2), are slightly lower but still indicate a highly effective system, with efficiencies between 88% and 92%. The more challenging nature of wet mud, due to its adhesive and cohesive properties, logically accounts for this minor reduction in performance.

Table 3 shows that with initial mud coverage of 100% for all samples, wet mud removal efficiencies range from 88% to 92%. Cleaning times are longer than for dry mud, varying from 8 seconds (Sample 4) to 11 seconds (Sample 2), with most samples requiring about 9 – 10.5 seconds. Sample 1 achieved the highest removal of 92% in 9 seconds, while Sample 5 recorded the lowest removal of 88% in 9 seconds. Overall, the results indicate consistent performance under wet mud conditions, with slightly reduced efficiency and increased cleaning time due to the viscous nature of wet soil.

**Table 3:** Wet Mud Removal and Cleaning Time

| Test Sample | Initial Mud Cover Page (%) | Wet Mud Recommend (%) | Cleaning Time |
|---|---|---|---|
| 1 | 100 | 92 | 9 |
| 2 | 100 | 89 | 11 |
| 3 | 100 | 91 | 10 |
| 4 | 100 | 90 | 8 |
| 5 | 100 | 88 | 9 |
| 6 | 100 | 91 | 10.5 |

### 3.2.1 Formula for Efficiency

The general formula for efficiency based on the data could be:

$$Efficiency = \frac{Mud\ Removal}{Percentage\ Cleaning\ Time\ (Seconds)} \tag{16}$$

This formula gives us the mud removal percentage per unit of time, effectively showing how much mud is removed for each second spent cleaning

**Steps to Calculate Efficiency for Each Sample**

For each sample, divide the **wet mud removal percentage** or **dry mud removal percentage** by the **cleaning time** in seconds. Higher values of this ratio would indicate higher efficiency, as more mud is removed in less time.

### 3.1.1 Example Calculation for Wet Mud Removal

Let's calculate the efficiency for each sample using the **wet mud removal** data.

$$Sample\ 1: \quad Efficiency = \frac{92\%}{9\ Seconds} = 10.22\%\ per\ Seconds$$

$$Sample\ 2: \quad Efficiency = \frac{89\%}{11\ Seconds} = 8.09\%\ per\ Seconds$$

$$Sample\ 3: \quad Efficiency = \frac{91\%}{10\ Seconds} = 9.1\%\ per\ Seconds$$

$$Sample\ 4: \quad Efficiency = \frac{90\%}{8\ Seconds} = 9.1\%\ per\ Seconds$$

$$Sample\ 5: \quad Efficiency = \frac{88\%}{9\ Seconds} = 9.78\%\ per\ Seconds$$

$$Sample\ 6: \quad Efficiency = \frac{91\%}{10.5\ Seconds} = 8.67\%\ per\ Seconds$$

### 3.1.1 Example Calculation for Dry Mud Removal

Similarly, you can calculate the efficiency using the **dry mud removal** data:

$$Sample\ 1: \quad Efficiency = \frac{98\ \%}{5\ Seconds} = 19.6\ \%\ per\ Seconds$$

$$Sample\ 2:\quad Efficiency = \frac{95\%}{9\ Seconds} = 16\%\ per\ Seconds$$

$$Sample\ 3:\quad Efficiency = \frac{97\ \%}{5\ Seconds} = 19.4\%\ per\ Seconds$$

$$Sample\ 4:\quad Efficiency = \frac{95\%}{7\ Seconds} = 13.57\%\ per\ Seconds$$

$$Sample\ 5:\quad Efficiency = \frac{99\%}{4\ Seconds} = 24.75\%\ per\ Seconds$$

$$Sample\ 6:\quad Efficiency = \frac{97\%}{6\ Seconds} = 16.17\%\ per\ Seconds$$

## 3. CONCLUSION

The practical implications of these results are substantial. The machine operates with an average cycle time of under 10 seconds, making it viable for high-traffic areas without causing disruptive bottlenecks. The touch-free activation, managed by the limit switch, enhances user compliance and eliminates a common point of cross-contamination found in manual systems. Combined with the strategic use of locally sourced materials, these results confirm that the machine is not only an effective disinfecting device but also a cost-effective, sustainable, and practical solution tailored for deployment in a wide range of settings, from resource-conscious environments to modern healthcare facilities. This study successfully designed, fabricated, and tested a shoe sole disinfecting machine combining mechanical brushing and UV-C sterilization. The prototype achieved up to 99% dry mud removal and 92% wet mud removal within 10 seconds, proving its high efficiency and practicality. It offers an eco-friendly, durable, and affordable solution suitable for hygiene-sensitive environments such as hospitals and offices.

## 3. RECOMMENDATIONS

Based on the findings of this study, it is recommended that future work focus on quantitative microbiological testing to validate the machine's efficacy in achieving pathogen log reduction, alongside exploring design refinements such as a pre-cleaning air blower or a safety-interlocked enclosure to enhance performance and user safety. Furthermore, long-term durability studies and a detailed market analysis should be conducted to ensure the product's reliability and commercial viability for widespread adoption, particularly in resource-conscious settings.

## NOMENCLATURE

| | |
|---|---|
| kW | Kilowatt |
| Km/h | Kilometer per hour |

## ABBREVIATIONS

| | |
|---|---|
| UV | Ultraviolet |
| DC | Direct Current |

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