International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Design and Implementation of A Robotic Car with A ULV Atomizer for Mosquito Control in Urban Parks

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Abstract

Mosquito infestations in tropical regions, particularly during months of moderate to high rainfall, pose significant health risks due to diseases like Malaria, Dengue, and Chikungunya. Traditional control methods such as fumigation and chemical sprays face limitations of environmental concerns and potential health risks to humans. To address this issue in community parks, I developed a robotic car equipped with an atomizer to disperse an organic mosquito repellent. Powered by a Raspberry Pi 4 and brushless DC motors, the robotic vehicle is designed for stable and efficient movement across uneven park terrains. It is controlled via an integrated PlayStation 4 controller for user-friendly operation. The atomizer disperses a repellent from essential oils such as Neem (Azadirachta indica), Lemongrass, and Eucalyptus, offering an environmentally friendly and human-safe alternative to chemical repellents like DEET. Testing indicated that the robotic car equipped with an atomizer effectively reduces mosquito presence, enhancing the safety and enjoyment of outdoor recreational spaces.

Keywords*:* mosquito control, robotic car, organic repellent, essential oils, community parks

Introduction

This section provides a comprehensive overview of the various habitats in which mosquitoes thrive, the incidence and impact of mosquito-borne diseases, and the environmental concerns associated with traditional mosquito control methods. It highlights mosquitoes' adaptability to different environments and the ecological consequences of commonly used control practices. This background sets the stage for exploring alternative, environmentally friendly solutions, such as organic repellents, that can mitigate the negative impacts of conventional methods.

Mosquitoes and their habitats

sMosquitoes, belonging to the family *Culicidae*, are a diverse group of small flies in various habitats worldwide. Their adaptability to different environments is crucial to their survival and proliferation. These habitats can be broadly categorized into three main types: natural, artificial, and transient.

Natural habitats

Mosquitoes thrive in natural water bodies such as ponds, marshes, swamps, and wetlands. These environments provide ample breeding grounds due to stagnant or slow-moving water, which is essential for the larval stages of mosquito development. Specific species, like *Anopheles* mosquitoes, which are primary vectors for malaria, are often found in rural and semi-rural areas with abundant vegetation and water bodies.

Artificial habitats

Urbanization has led to the creation of numerous artificial habitats conducive to mosquito breeding. Man-made structures such as water tanks, drainage ditches, and discarded tires can accumulate water, providing ideal conditions for species like Aedes aegypti, a known vector for dengue fever, Zika virus, and chikungunya. Mosquitoes' adaptability to these environments underscores the importance of proper waste management and urban planning in mosquito control strategies.

Transient habitats

Some mosquito species have adapted to temporary water bodies such as puddles, hoof prints, and floodwaters. Mosquitoes such as Culex species often utilize these transient habitats, which are common vectors for diseases like West Nile virus. The ephemeral nature of these water bodies necessitates rapid development and short life cycles in these mosquito species, facilitating their spread during rainy seasons.

Environmental Concerns of Traditional Control Methods

Traditional mosquito control methods have been widely used to reduce mosquito populations and minimize the spread of mosquito-borne diseases. While these methods can effectively control mosquito populations, they often have significant environmental impacts. Understanding these impacts is crucial for developing sustainable mosquito control strategies that protect public health without harming the environment.

Chemical Insecticides:

Using chemical insecticides, such as DDT, malathion, and pyrethroids, can negatively affect non-target species, including beneficial insects, birds, fish, and amphibians. These chemicals can reduce biodiversity by killing organisms that play crucial roles in ecosystems, such as pollinators and natural predators of pests. Overuse of chemical insecticides can lead to the development of resistance in mosquito populations. Resistant mosquitoes are more challenging to control and may require higher doses or more toxic chemicals, exacerbating environmental damage and reducing the effectiveness of control measures. Chemical insecticides can contaminate water bodies through runoff, posing risks to aquatic ecosystems. Contaminated water can affect the health of fish and other aquatic organisms, disrupt food chains, and degrade water quality, impacting wildlife and human communities.

Larvicides:

Larvicides, such as temephos and *Bacillus thuringiensis israelensis* (Bti), target mosquito larvae in water bodies. While Bti is generally considered environmentally friendly, temephos and other chemical larvicides can harm non-target aquatic organisms, including crustaceans, fish, and insect larvae essential to the ecosystem. Reducing mosquito larvae can alter aquatic ecosystems by affecting the species that prey on them. This can disrupt food webs and lead to unintended ecological consequences.

Habitat Modification:

Draining wetlands to reduce mosquito breeding sites can have severe environmental impacts. Wetlands are critical habitats for many species, including migratory birds, amphibians, and fish. They also play essential roles in water purification, flood control, and carbon sequestration. Wetland drainage can lead to habitat loss, decreased biodiversity, and disrupted vital ecosystem services. Removing vegetation to eliminate mosquito breeding sites can result in soil erosion, wildlife habitat loss, and reduced plant diversity. Vegetation serves as a habitat and food source for various species, and its removal can have cascading effects on the ecosystem.

Environmental Contamination:

Chemical insecticides can persist in the soil, affecting soil health and microorganisms. This can reduce soil fertility, alter nutrient cycles, and impact plant growth. Persistent soil pollution can have long-term ecological effects and affect agricultural productivity. Spraying insecticides can release volatile organic compounds (VOCs) and other chemicals into the air, contributing to air pollution. This can affect human health and the health of terrestrial and aquatic organisms exposed to airborne chemicals.

Research question

How effective is a four-wheel robotic car equipped with an atomizer in reducing mosquito populations in community spaces by dispersing organic mosquito repellent?

Objectives of the study

Evaluate the Effectiveness:

To assess the effectiveness of the four-wheel robotic car in reducing mosquito populations in community spaces by dispersing an organic mosquito repellent.

Design and Implementation:

To design and build a four-wheel robotic car equipped with an atomizer to disperse organic mosquito repellent in community spaces.

Operational Efficiency:

To determine the robotic car's operational efficiency and coverage area within various park settings.

Environmental Impact:

The aim is to analyze the environmental impact of using an organic mosquito repellent dispersed by the robotic car compared to traditional chemical methods.

Usability Assessment:

To evaluate the ease of use and user acceptance of the robotic car among community members and maintenance staff.

Health and Safety:

To investigate the health and safety benefits for park visitors by using the robotic car to reduce the incidence of mosquito-borne diseases.

Significance of the study

This study aims to demonstrate the feasibility and benefits of integrating robotics and organic repellents into mosquito control strategies, potentially setting a new standard for sustainable pest management practices in urban environments.

Innovative Solution:

This study introduces a novel, technology-driven solution to the persistent problem of mosquito control in community parks, addressing the limitations of traditional methods.

Public Health Improvement:

The robotic car can help lower the incidence of mosquito-borne diseases by effectively reducing mosquito populations, thereby improving public health and reducing the burden on healthcare systems.

Environmental Benefits:

Using organic repellents and a targeted delivery system minimizes environmental contamination and reduces harm to non-target species, promoting a more sustainable approach to mosquito control.

Enhanced Outdoor Experience:

Ensuring safer and more enjoyable outdoor environments for community members by reducing mosquito presence in parks and recreational areas.

Cost-Effectiveness:

The robotic car could offer a cost-effective alternative to traditional mosquito control methods by reducing the need for frequent chemical applications and associated labor costs.

Scalability and Adaptability:

The technology can be adapted and scaled for use in various settings beyond community parks, including schools, residential complexes, and other public spaces, broadening its impact.

Methodology

The methodology section details the processes and procedures involved in the research. It includes the following components:

System Design and Development

Design assumptions

- The robot should be user-friendly (i.e., easy to control and operate)
- The robot should be man-portable and light, with a weight not exceeding 15kg
- Must have the capacity to operate for a minimum of 30 minutes and spray a minimum area of 4000 square meters with a single tank

Hardware Assembly:

The robotic car includes various hardware components, such as the Raspberry Pi 5 for processing, brushless DC (BLDC) motors for propulsion, an axle-based system for stable movement, a lithium-ion battery for power, a PS4 controller for manual operation, an atomizer for dispersing repellent, and DC to DC converters for managing voltage requirements.

Software Development:

Development focused on creating control software for the Raspberry Pi, which includes navigation algorithms for path planning, motor control logic for maneuvering the car, and a user interface for operating the vehicle via the PS4 controller.

Field Testing

Test Sites:

Community parks with varying mosquito infestation levels were selected as test sites to ensure diverse environmental conditions.

Operational Testing:

The robotic car was deployed in these selected parks and operated to disperse the organic mosquito repellent.

Effectiveness Analysis

Effectiveness Analysis:

A comparison of mosquito population data before and after treatment was conducted to evaluate the system's effectiveness.

Comparative Analysis:

The results were compared with data from traditional mosquito control methods employed in similar environments, utilizing a feedback mechanism to gather insights.

User Feedback:

Feedback was collected from community and park users regarding the usability and effectiveness of the robotic car system.

Expected Outcomes

Reduction in Mosquito Populations:

A significant decrease in mosquito populations is expected in the treated areas.

Enhanced Safety and Comfort:

Using an organic repellent aims to improve safety and comfort for park users.

Environmental Impact:

The system is expected to have a reduced environmental impact compared to traditional chemical-based methods.

Operational Efficiency:

High user satisfaction with the ease of operation and the effectiveness of the robotic car is anticipated.

Limitations

Environmental Factors:

The effectiveness of the repellent may vary depending on weather conditions, such as wind and rain, and park-specific characteristics, such as flora density and park upkeep.

Operational Challenges:

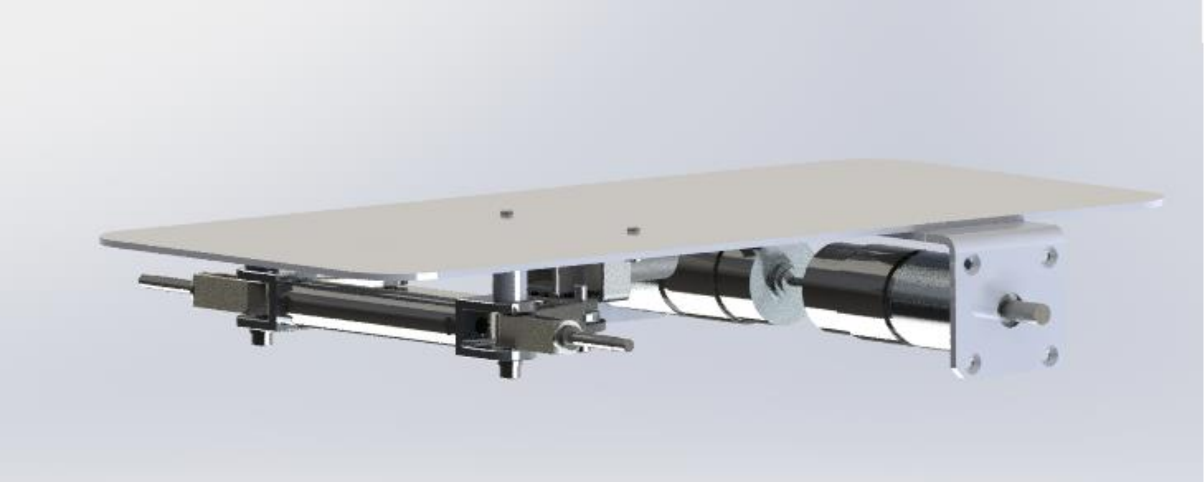
Potential capacity issues related to the robotic car's navigation, battery life, and repellent dispersion.

Justification for chosen methods

System design and development

Chassis and Structural Design

The chassis of the robotic car was constructed using aluminum sheet metal due to its durability, lightweight nature, and corrosion resistance. This choice ensures a robust frame capable of withstanding various terrains (pavement, grass, loose soil, etc) encountered in community parks. The chassis was personally fabricated, with all necessary holes for screw mounts to secure components firmly.



Motor Selection and Axle Design

A Brushless DC (BLDC) motor was chosen for propulsion due to its high efficiency, reliability, and low maintenance requirements. BLDC motors provide superior speed control and torque performance, which is ideal for the varied terrain of community parks. An axle system with an L-shaped DC motor was included to ensure precise control and stability, essential for navigating uneven surfaces.

Torque Calculation. The torque calculations determine the necessary rotational force for the wheels, ensuring the robotic car can overcome resistance and achieve the desired motion. This is crucial for selecting a motor with adequate power and efficiency for optimal performance.

$$total\ mass\ of\ car(m) = 10KG$$

$$wheel\ diameter = 110\ mm(radius = 55mm)$$

$$coefficient\ of\ static\ friction(\mu) = 0.3$$

$$slope(\alpha) = 10°$$

$$RPM\ of\ wheel = 100$$

$$maximum\ velocity\ of\ car\ (Vmax) = 0.6\,m/s$$

$$Time\ taken\ to\ reach\ maximum\ velocity\ (t) = 1s$$

$$front\ surface\ area\ of\ car\ (A) = 350 \times 350mm$$

$$coefficient\ of\ drag(Cd) = 1.4$$
$$pressure\ at\ sea\ level\ (\rho) = 1.225\ kg/m^3$$
$$total\ tractive\ (pulling)\ force = Ft = Fs + Fg + Fa + Fd$$
$$Fr = force\ necessary\ to\ overcome\ static\ friction$$
$$Fr = m \times g \times \mu \times \cos\alpha$$
$$Fr = 10 \times 9.81 \times 0.3 \times \cos 10$$
$$Fr = 29N$$
$$Fg = force\ required\ to\ climb\ a\ gradient$$
$$Fg = m \times g \times \sin\alpha$$
$$Fg = 10 \times 9.81 \times \sin 10$$
$$Fg = 17N$$
$$Fa = force\ required\ to\ accelerate\ till\ final\ velocity$$
$$Fa = m \times Vmax \div T$$
$$Fa = 10 \times 0.6 \div 1$$
$$Fa = 6N$$
$$Fd = force\ required\ to\ overcome\ drag$$
$$Fd = {}^{1}\!/_{2} \times Cd \times \rho \times A \times Vmax^2$$
$$Fd = {}^{1}\!/_{2} \times 1.4 \times 1.225 \times 0.35 \times 0.35 \times 0.6^2$$
$$Fd = 0.04N$$
$$Ft = Fr + Fg + Fa + Fd$$
$$Ft = 29 + 17 + +6 + 0.04$$
$$Ft = 52.04N$$
$$torque\ required\ to\ rotate\ the\ wheel(T) = Ft \times wheel\ radius$$
$$T = 52.04 \times 0.055$$
$$T = 2.9Nm$$
$$power\ required\ to\ rotate\ the\ wheel(P) = {}^{2\pi nT}\!/_{60}$$
$$P = 2 \times 3.14 \times 1002.9 \div 60$$
$$P = 30.4\ Watt$$
$$gear\ efficiency = 70\%$$
$$motor\ efficiency = 80\%$$
$$saftey\ factor = 2$$
$$motor\ power\ required = \frac{30.4 \times 2}{0.7 \times 0.8}$$
$$motor\ power\ required = 108.6\ Watt$$

The motor power required to run the system is used in Table 1 and Table 2 below for power budget calculation.

Motor Driver and Processing Unit

An appropriate motor driver (Cytron MDD10A REV 2.0) was selected to match the specifications of the BLDC and DC motors, ensuring optimal performance and efficient power management. The Raspberry Pi is the central processor chosen for its ease of programming, versatility, and strong community support.

It is compatible with various sensors and modules for future upgrades and can run complex algorithms, making it an ideal choice for controlling the robot's functions.

Power System

The power system is centered around a 12V lithium-ion battery, chosen for its high energy density and lightweight nature. A DC-DC converter steps down the voltage from 12V to 5V, providing a stable power supply to the Raspberry Pi and preventing potential damage from voltage fluctuations.

Power budget calculation. The power budget calculations outline the energy requirements for all system components, ensuring that the robotic car operates efficiently within the constraints of the available battery capacity. This includes estimating the power consumption during different operation modes and optimizing battery usage for maximum endurance.

Table 1 - POWER CONSUMPTION – ATOMISER WITH DRIVE

SR.NO.	DEVICE	CURRENT DRAWN	POWER CONSUMPTION IN WATTS	BATTERY POWER AVAILABLE	OPERATIONAL HOUR
1.	Microcontroller Power 5V	4 Amps	20 Wh	288 Wh	0.625 hours or 37.5 Minutes
2.	DC Motor Power @ 12 V	9 Amps	108 Wh		
3.	Atomizer spray Power @ 24 V	10 Amps	240 Wh		
4.	Total Power consumption		314 Wh		
5.	Battery Capacity	80%		230 Wh	

$$total\ power\ consumption = 20 + 108 + 248 = 368\ watt$$

$$power\ available = voltage \times ampehre\ hour$$

$$power\ available = 12 \times 24 = 288\ watt\ hour(Wh)$$

$$at\ 80\%\ battery\ efficiency = 288 \times \frac{80}{100} = 230\ Wh$$

$$system\ endurance\ during\ full\ operation = \frac{230}{368} = 0.625\ hours = 37.5\ minutes$$

Table 2 - POWER CONSUMPTION – DURING DRIVE ONLY

SR.NO.	DEVICE	CURRENT DRAWN	POWER CONSUMPTION IN WATTS	BATTERY POWER AVAILABLE	OPERATIONAL HOUR

1.	Microcontroller Power 5V	4 Amps	20 Wh	288 Wh	1.8 Hours or 108 Minutes
2.	DC Motor Power @ 12 V	9 Amps	108 Wh		
3.	Power Consumption		128 Wh		
4.	Battery Capacity	80%		230 Wh	

$$system\ endurance\ during\ drive = \frac{230}{128} = 1.8\ hours = 108\ minutes$$

Atomizer Selection

There are three different types of devices that disperse liquid in the air: foggers, Electrostatic sprayers, and ultra-low-volume (ULV) atomizers. Comparing each provides their distinct features and benefits in certain use cases.

Foggers disperse disinfectants as fine mist particles, typically covering large areas and getting into nooks and crannies. However, they often require longer drying times and may leave a residue. They are commonly used for general disinfection in large open spaces but might not ensure even coverage and tend to disperse with the slightest change in the wind velocity.

Electrostatic sprayers charge disinfectant particles, causing them to adhere evenly to surfaces. This method is highly efficient, reducing chemical use by up to 65% and application time by up to 70% compared to traditional methods. The charged particles wrap around surfaces, providing thorough coverage even in hard-to-reach areas. These sprayers are particularly effective when quick disinfection is needed, such as in healthcare or public transport.

ULV (Ultra-Low Volume) atomizers are highlighted as a top choice for disinfection due to their ability to produce ultra-fine droplets (below 50 microns). This allows for a fine mist that can evenly coat surfaces with minimal liquid, which speeds up drying time and reduces the risk of over-application. ULV atomizers are versatile and can be used for large and small areas, making them suitable for various applications. They offer an excellent balance between efficacy, coverage, and cost-efficiency, making them a preferred option for routine use.

An Ultra-Low Volume (ULV) atomizer was selected for dispersing mosquito repellent, offering several benefits:

Efficiency. Produces a fine mist for even coverage and effective mosquito control using less liquid repellent.

Safety. It operates at lower temperatures, making it safer for use in populated areas than a hot fogger.

Environmental Impact. Reduces chemical usage, minimizing ecological impact and the risk of chemical resistance in mosquito populations.

Mosquito Repellents

Mosquitoes are significant vectors for various diseases, including malaria, filariasis, Japanese encephalitis, dengue fever, chikungunya, Zika fever, Mayaro, and yellow fever. They are primarily attracted to carbon dioxide, warmth, humidity, and specific chemicals in human sweat. This attraction makes mosquito repellents a practical and economical means to reduce or prevent mosquito-borne diseases by masking the chemical cues that attract mosquitoes.

Chemical Mosquito Repellents

1. DEET (N, N-diethyl-meta-toluamide): A widely used active ingredient in repellents, available in various forms like liquids, lotions, and sprays.
2. Picaridin: Known for its effectiveness comparable to DEET, with a lower risk of irritation. It is often preferred for its favorable safety profile.

While chemical repellents do not pose significant risks when used properly, they may cause irritation, redness, or other issues if misused. Additionally, these chemicals can contribute to environmental pollution and general toxicity.

Herbal Mosquito Repellents

Herbal repellents are considered safer alternatives to chemical ones, as they typically have low toxicity for humans and animals. They are often derived from essential oils and natural extracts known for their repellent properties. Some commonly used essential oils include:

1. Lemon Eucalyptus Oil: The CDC has approved this effective ingredient, offering over 95% protection for approximately 3 hours.
2. Neem Oil: Although its effectiveness varies, some studies suggest it provides over 70% protection for up to 3 hours.
3. Citronella Oil: The U.S. Environmental Protection Agency recognizes citronella oil as a biopesticide with non-toxic effects. It is a widely used natural repellent.

Example of Herbal Mosquito Repellent

MOSPRAY (https://herbalstrategi.com/products/herbal-mosquito-repellent-body-spray?variant=43674851082478), an herbal mosquito repellent by Herbal Strategi, contains natural ingredients like Bhutika Oil (Cymbopogon citratus), Rohisha Oil (Cymbopogon martini), Tulsi Oil (Ocimum sanctum), and Tallaparna Oil (Eucalyptus globulus) in a water-based formulation. This combination provides a safer and environmentally friendly alternative to chemical repellents.

Spray Pattern and Effectiveness

Experimental Observations

Water (as a comparison).

- Spray particles are seen drifting away beyond 5m at a height >3m.
- The pattern was dispersive and influenced by wind.

Organic Repellent (5% diluted in water)

- Felt up to 6.5m with lesser side dispersion.
- Spray particles are seen drifting away beyond 6.5m, especially in windy conditions.

***Conclusion*:**

Droplet Distance. Oil-based droplets traveled farther due to higher viscosity and greater momentum.

Environmental Factors. Wind significantly affects spray patterns, necessitating adjustments based on area and conditions to ensure effectiveness.

Repellent Delivery. For optimal operation, the system's setup needs to account for practical variables like wind and droplet characteristics.

Results and Conclusion

Effectiveness of the Robot

The robotic car designed for spraying mosquito repellent in community parks has shown promising results in performance, ease of use, and efficiency. Key findings from the field tests are as follows:

Coverage and Efficiency

The robot effectively covered the designated area by uniformly dispersing the mosquito repellent. Using an Ultra-Low-Volume (ULV) atomizer ensured fine mist distribution, leading to efficient use of the repellent with minimal waste. The robot could cover an area of 1,000 square meters in approximately 4 minutes using 0.5 liters of the repellent mixture, which is comparable to the time required for hot fogging. Given that the solution costs 50 rupees per liter, the cost of spraying 1,000 square meters is 25 rupees. For comparison, the average price of a chemical repellent for the same area is 36 rupees.

Battery Performance

During full operation (driving and spraying), the robot's operational time with the 12V/24AH battery was approximately 40 minutes, indicating endurance.

Motor and Torque Performance

The chosen motors provided adequate torque to navigate various terrains within the park, including inclines and uneven surfaces. The calculated torque and power requirements matched the real-world performance, ensuring reliable and smooth operation.

Safety and Environmental Impact

Using an organic repellent minimized health risks for humans and animals, with no observed adverse effects on the park's ecosystem. The robot's semi-automated operation reduced human exposure to chemicals, enhancing safety.

Effect on non-target species

Studies indicate that thermal fogging can result in significant mortality among non-target arthropods, including beneficial insects such as pollinators and natural pest predators. This can lead to changes in the soil's microbial composition, potentially affecting fertility and the overall health of the soil ecosystem. Using a ULV atomizer with an organic repellent was beneficial in this aspect, too, as this system doesn’t affect non-target species and thus doesn’t lead to ecological imbalance or changes in the food web.

Repellent Effectiveness

Field observations confirmed that the organic repellent effectively reduced mosquito activity in the treated areas, reducing approximately 50-60% during the application period. The repellent demonstrated a noticeable impact, with its effectiveness lasting for about 3-5 hours before reapplication was needed. This indicates that while the repellent initially provided significant protection, periodic reapplication was required to sustain its efficacy.

User Feedback

Feedback from park visitors and maintenance staff was cheerful, highlighting the robot's efficiency and the reduced mosquito presence. The robot’s autonomous operation was particularly appreciated for its convenience and the reduced need for manual intervention. Additionally, users reported no adverse effects from the organic repellent, such as respiratory problems, indicating that it is safe for human contact and use in public spaces. The dispersive spray pattern of the repellent effectively covered a large area, maximizing its reach and ensuring that a significant portion of the treated space received its protective benefits. Overall, the combination of reduced mosquito activity, user safety, and broad coverage, along with the robot's efficiency, underscores the effectiveness of the organic repellent in managing mosquito populations in the treated areas.

Conclusion

Overall, the robotic car has proven to be a practical and effective solution for mosquito control in community parks, combining efficient repellent dispersion, safe operation, and positive environmental impact. It efficiently disperses organic repellent, covering 1,000 square meters in about 4 minutes with minimal waste. The robot’s battery performance and motor capabilities ensure reliable operation across various terrains. Organic repellent minimizes health risks and environmental impact, avoiding harm to non-target species and maintaining ecological balance. Field observations confirm a significant reduction in mosquito activity (50-60%) for 3-5 hours, with positive feedback from users highlighting the robot’s efficiency and safety. Overall, the robot’s effectiveness, convenience, and minimal environmental impact underscores its potential for broader application and further optimization. Further optimization and scaling can enhance its applicability to larger areas and different environments.

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