OPTIMIZATION OF NONCONVENTIONAL UV EMISSION PILLAR OF THE AUTONOMOUS MOBILE PLATFORM THROUGH STRUCTURAL ANALYSISCS

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ABSTRACT: The present study is dedicated to a meticulous optimization process of the UV emission pole on an autonomous mobile platform, employing structural analysis and the finite element analysis program ANSYS. Through sophisticated simulations, a comprehensive evaluation of the forces and stresses to which the pole is subjected under diverse operational conditions is meticulously executed, thereby facilitating the identification of critical junctures and potential enhancements pertaining to the geometry or materials employed. The finite element analysis conducted in ANSYS offers a precise modus operandi for modelling the structural behaviour of the pole. This method allows for the simulation of authentic operating conditions, thereby providing a comprehensive framework for evaluating the efficacy of the extant project. Furthermore, the finite element analysis facilitates the visualization of deformations and stress distributions, thereby yielding invaluable insights for the optimization endeavour. Through the implementation of this advanced analytical program, the study proffers a scholarly and technical approach toward comprehending and refining the performance of the UV emission pole. This integrated research methodology proclaims noteworthy contributions to the realm of technological development, ensuring a robust foundation for design and optimization determinations within the domain of autonomous mobile platforms.

KEYWORDS: optimization, structural analysis, finite element analysis, UV emission pole, autonomous mobile platform

1. INTRODUCTION

The objective of this research paper is to enhance the current design of an autonomous mobile platform equipped with a UV disinfection system. This will be accomplished by identifying existing issues and proposing effective solutions that do not compromise the overall design of the mechatronic assembly. In today's context, disinfection technologies are increasingly crucial, particularly in healthcare and industrial environments where hygiene and sterilization are paramount.

Autonomous mobile platforms equipped with UV disinfection systems have emerged as modern and efficient solutions for reducing the risk of contamination in large or hard-to-reach spaces. [1], [2], [3]

Before undertaking any optimization efforts for this platform, it is necessary to conduct an in-depth assessment of the existing issues. This involves analysing the technical, operational, and user-related challenges to gain a complete understanding of the areas that require improvement.

These may include constraints in manoeuvrability and energy efficiency, as well as concerns regarding safety during use and the effectiveness of disinfection.

Although existing UV disinfection systems are proficient in eradicating microorganisms, they necessitate precise radiation distribution to ensure

thorough and uniform disinfection.

Therefore, any design enhancements should focus on improving this distribution without compromising the platform's mobility or the stability of the mechatronic assembly.

In addition to the technical aspects regarding the UV system's efficiency, we will pay particular attention to seamlessly integrating new solutions without substantially altering the platform's fundamental structure.

This approach is crucial for maintaining production costs at an optimal level and for enabling future upgrades of the equipment. The proposed solution will prioritize the replacement or reconfiguration of specific components to enhance the platform's robustness, energy efficiency, and durability in operation.

The paper focuses on achieving a balance between performance, efficiency, and sustainability.

It offers an innovative solution to enhance the current design of the autonomous mobile platform with a UV disinfection system without compromising its fundamental structure. [4], [5]

2. THE OPERATIONAL PRINCIPLE OF THE MOBILE PLATFORM, WHICH FACILITATES THE IDENTIFICATION OF THE ISSUE

As we know, the Autonomous Mobile Platform with UV Ray Disinfection System operates along a predefined path, relying on a series of QTR8A reflective sensor modules connected in sequence. This configuration, consisting of five QTR-8A sensors, is designed for line tracking and can also function as a proximity or general-purpose object detection sensor, as illustrated in Figure 1.

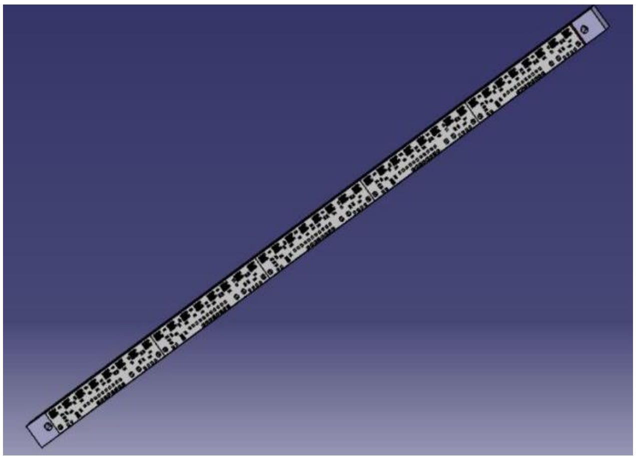

Figure 1. The QTR8A sensors

With a differential drive mechanism, the platform follows the line by keeping two or, depending on the line width, even three sensors positioned above it. If the central sensors detect the line, the platform receives the necessary signal to move forward at cruising speed—a speed lower than the maximum speed—in the positive direction, as shown in Figure 2.

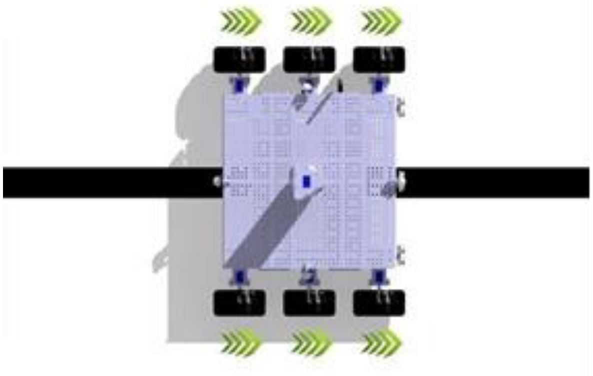

Figure 2. The movement of platform in a straight line

Ideally, the platform should follow a straight line, keeping the central sensors aligned. However, in practice, deviations from the ideal line can occur, which the platform must manage, as indicated in Figure 3.

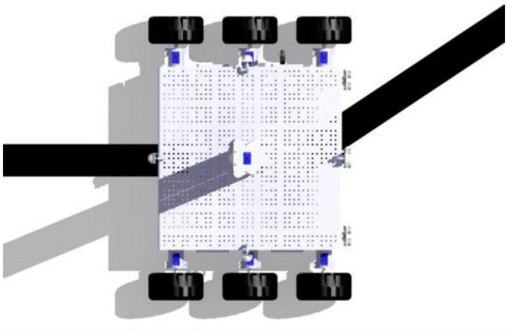

Figure 3. The observation of a deviation

When the platform encounters a deviation from the predefined line, flagged as an error in the code, several correction options are available. A straightforward solution, shown in Figure 4, is for the platform to command the right wheels to reach maximum speed while the left wheels rotate in the same direction but at a lower speed.

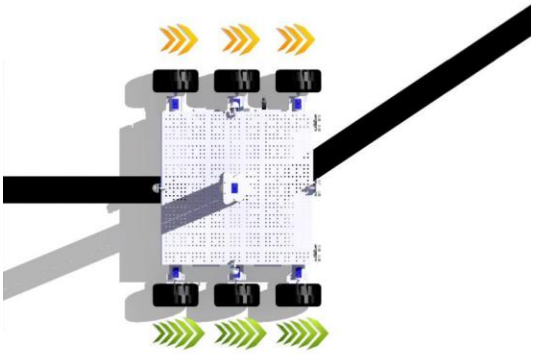

Figure 4. The first method to interpret a deviation

Alternatively, as shown in Figure 5, the platform can signal the right wheels to achieve maximum forward speed while the left wheels rotate at maximum speed in the reverse direction for an efficient correction.

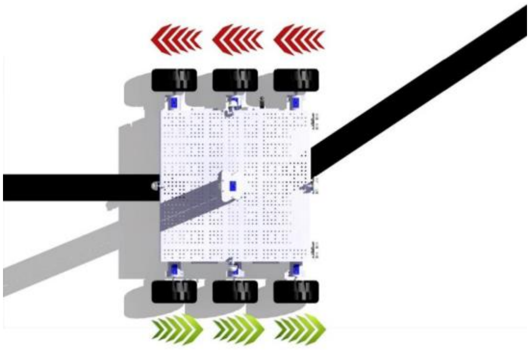

Figure 5. The second method to interpret a deviation

Both options are effective and allow the platform to return to the correct trajectory. Along the route, the platform has strategically placed points marked with QR codes, which it must read using the onboard camera. For this purpose, the platform has two deceleration points positioned before the QR codes and a stopping point located 110 mm after each QR code, considering the position of the ESP32 camera relative to the QTR8A sensor bar.

The first deceleration point is placed 2 meters from the QR code and signals the platform to reduce its speed to 50% of the usual speed.

The second deceleration point, located 1 meter from the code, signals a further reduction to 25% of the usual speed, allowing for precise code reading without a full stop, as observed in Figure 6.

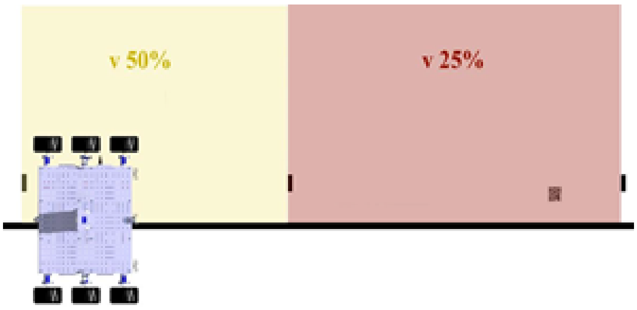

Figure 6. The platform braking

Based on the signal received after reading the QR code, as seen in Figure 7, the platform stops the motors and activates UV radiation for a predetermined duration set in the code, which can be configured to 10, 15, or 20 minutes.

These functionalities ensure precise and efficient navigation while also facilitating the UV disinfection process under controlled and configurable conditions. [6], [7]

Understanding the platform's operation reveals that the design of the UV emission post is not optimal for starting and changing direction in both correction cases, as shown in the Figures 8 and 9.

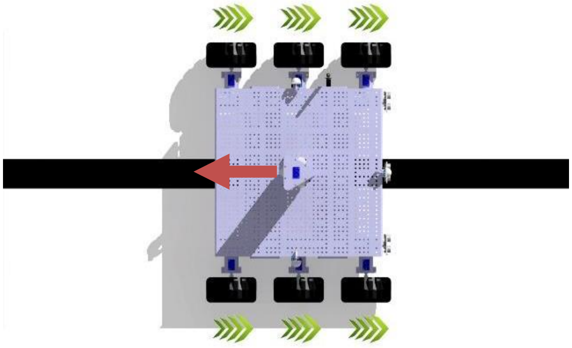

Figure 7. The influence of starting the platform on the pole

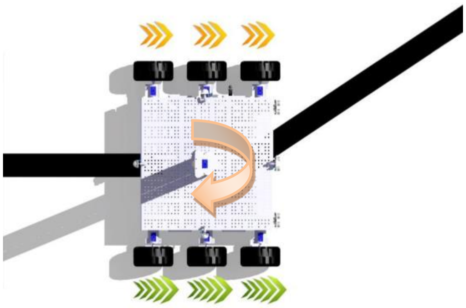

Figure 8. The influence of correction case I on the pole

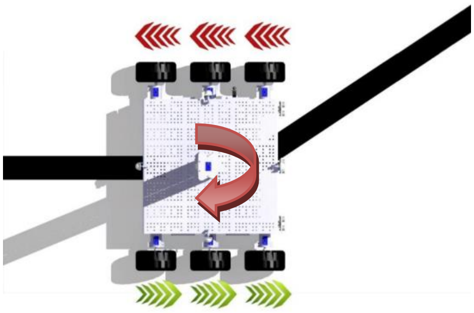

Figure 9. The influence of correction case II on the pole

3. STRUCTURAL ANALYSIS APPLIED TO THE ELEMENT

As presented in previous chapters, performs disinfection at strategic points marked by QR codes. These QR codes, encountered along the platform’s route, serve as checkpoints that inform the platform of its immediate tasks and guide it on subsequent actions. By scanning these codes, the platform receives instructions regarding disinfection points, where it must pause and activate its UV lamps to perform thorough sterilization. This QR code system provides essential navigation and operational cues, allowing the platform to efficiently execute its disinfection tasks in specific, high-traffic or contamination-prone areas.

Following a Failure Mode and Effects Analysis (FMEA), it was identified that due to the platform’s speed of 1.5 m/s and its geometric structure, it may experience strain or instability when restarting from these strategic QR-marked points or when adjusting for any line deviations encountered along its path. The FMEA findings highlight that, while the platform is functional for UV disinfection, its repeated stops and starts—especially at QR checkpoints—alongside sudden directional corrections, introduce mechanical stresses that could potentially impact the structural integrity of the UV lamp support (pole).

These stresses may accumulate over time, leading to possible deformation or fatigue within the lamp support structure, which could compromise the uniformity and effectiveness of UV exposure.

Given these findings, a static structural analysis is warranted to assess the platform’s resilience in these scenarios.

This analysis will evaluate the potential deformation and stress distribution on the lamp support when the platform repeatedly starts at QR codes and initiates corrective manoeuvres for line tracking.

The primary aim is to determine if these repetitive movements impose a level of strain that might ultimately weaken or deform the lamp support structure, which is critical for maintaining precise positioning and effective UV exposure (Figure 10).

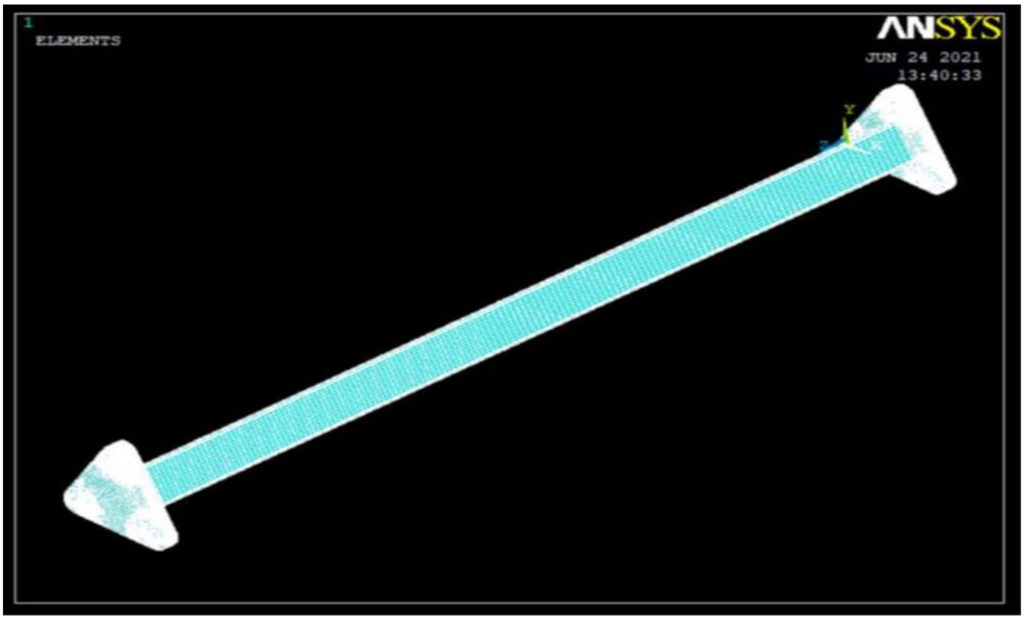

Figure 10. Lamp support modeled in Ansys 12 Mechanical APDL Product Launcher

To perform the structural analysis of the lamp support, the finite element analysis software Ansys 12 Mechanical APDL Product Launcher was used.

This software is well-known for its ability to simulate the structural behaviour of components under various loading conditions.

During the analysis, the lamp support model was created in detail to accurately reflect its geometry and materials, allowing for a realistic estimation of structural behaviour in practical situations.

Ansys 12 enabled the evaluation of stresses, deformations, and the distribution of forces within the support, helping to identify critical areas that might deform during system operation.

This simulation stage is essential for ensuring the safety and reliability of the structure in real-world use, with the information obtained being valuable for optimizing the final design.

The structural analysis performed on the element in the image aims to determine the maximum equivalent stress value, an essential parameter in evaluating the structural behaviour under loads.

The material used for this element is aluminum, a metal known for its combination of strength and low weight, making it ideal for applications where reduced mass and structural integrity are priorities.[8], [9]

The mechanical properties of aluminum include an elastic modulus of E = 70,000MPa, a material density of 2.7 * 10^{-6} kg/mm}^3, and a Poisson's ratio of ν = 0.3.

The elastic modulus provides a measure of the material's stiffness, indicating how much aluminum deforms under applied stress, while the Poisson's ratio indicates the ratio of transverse contraction to longitudinal elongation when the material is subjected to a load. In the finite element analysis (FEM), two types of finite elements were used, SHELL63 and SOLID45, which are suitable for simulating thin and solid structures, respectively.

The SHELL63 elements are employed to model the behaviour of thin plates, where both in-plane stresses and those occurring through the thickness of the material are analysed, while SOLID45 allows for the analysis of volumetric deformations and stresses in three-dimensional solid bodies. The use of these appropriate finite elements provides a detailed analysis of the stress distribution within the aluminum structure, highlighting critical areas that could be subject to excessive deformation under the applied load. The pressure applied to the aluminum element is 1.8 N, a value obtained from calculating the inertial force applied to the lamp supports.

This inertial force, denoted as Fi, is determined according to the relationship:

$$Fi= m \cdot a \text{ [N]} \quad (1)$$

where:

- m represents the total mass of the triangular profile and the upper base plate, valued at 1.2 kg;

- a is the applied acceleration, valued at 1.5 m/s^2

The calculation of the inertial force results in:

$$Fi= 1.2 \cdot 1.5 = 1.8 \text{ [N]} \quad (2)$$

This force is applied to the model, generating a stress distribution that allows for the analysis of the structural behaviour of the element under the specific load. The analysis seeks to determine the maximum equivalent stress, which is essential for assessing whether the structure can withstand the load without failing. By determining this value, it can be evaluated whether the aluminum element meets safety requirements to support the lamps without the risk of failure (Figures 11, 12 and 13).

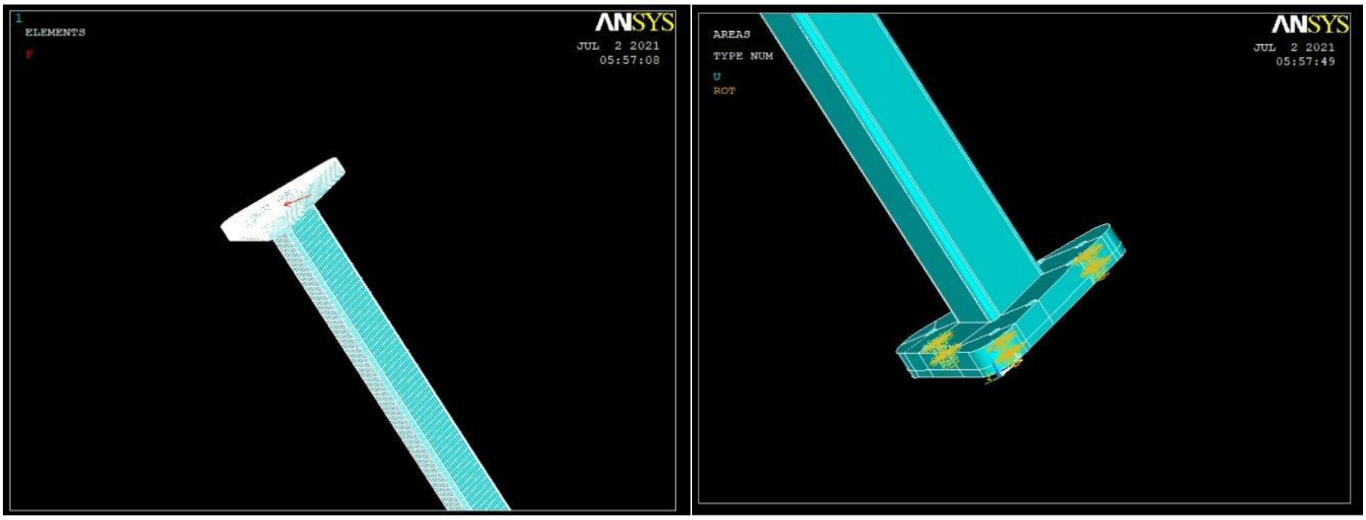

Figure 11. Application of concentrated force b. Embedded in the lower base plate of the autonomous mobile platfor

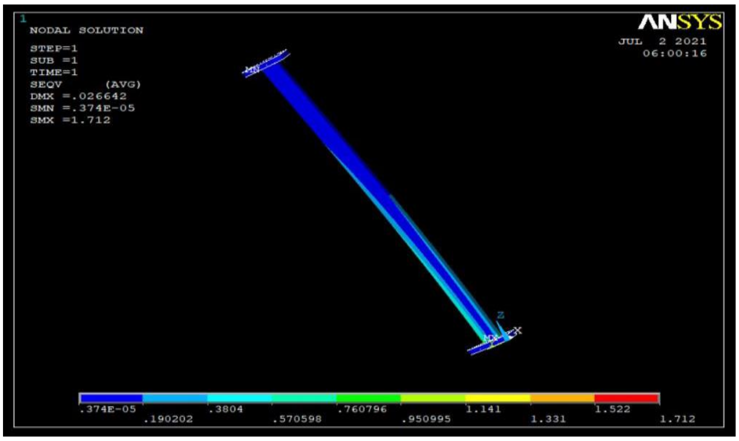

Figure 12. The result of the structural analysis

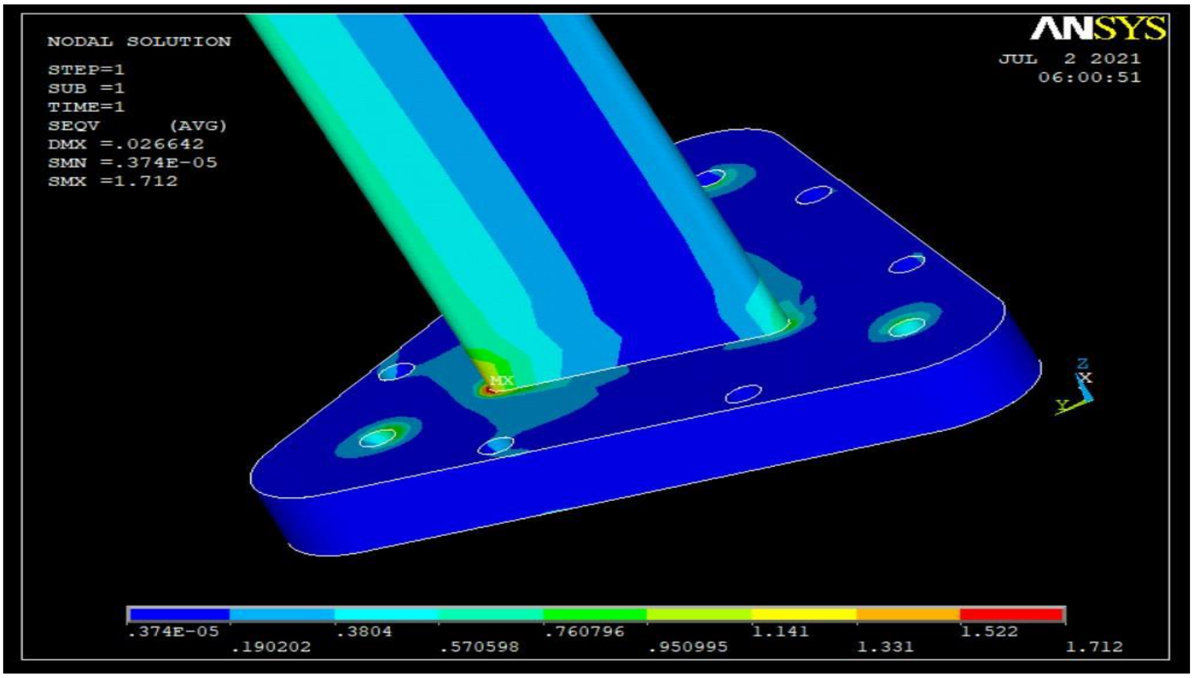

Figure 13. The most affected area

4. LAMP SUPPORT STABILIZATION STRATEGIES

4.1 Introduction of an Anchor into the System

An effective solution for preventing the deflection of the lamp support would be the introduction of an anchor to stabilize the structure. Anchoring could be achieved by securing the support to a more solid base, significantly reducing movement under load. This solution can lead to improved structural performance, but it requires careful analysis of the costs and resources necessary for implementation.
For example, anchors can be made from robust materials such as steel and may require an installation process that involves drilling into the support foundation. Additionally, considerations regarding design aesthetics and the long-term impact on the structure must also be addressed. The installation of anchors may necessitate periodic maintenance, which could incur additional costs over time. Furthermore, it is important to assess the technical feasibility of this solution, taking into account the specific environmental conditions in which the support is situated.

4.2 Introduction of an Elastomer into the System

Another approach would be to integrate an elastomer into the system to absorb vibrations and limit deflection.[10], [11]
Elastomers are known for their shock-absorbing properties and can provide an effective solution for reducing deformations. This could involve the use of elastic pads or rubber supports positioned between the lamp and the support, which would absorb energy from impacts and movements.
This solution has the advantage of being relatively easy to implement and requiring lower initial costs compared to other solutions. Additionally, elastomers are available in various degrees of stiffness, allowing for customization of the solution based on the specific needs of the support. However, the disadvantages of this method must also be considered, such as material degradation over time, which can lead to a loss of effectiveness in vibration absorption.

4.3 Modification of the Geometry of the Autonomous Mobile Platform

A more radical yet potentially effective solution would be to modify the geometry of the autonomous mobile platform. This solution could involve redesigning the support to provide a more uniform load distribution, which could reduce deflection. For instance, a more robust shape or a more complex design could enhance stability.

5. CONCLUSIONS

In the field of robotic engineering, managing the deflection of lamp supports in the autonomous mobile platform assembly equipped with a UV disinfection system is essential for ensuring the performance and reliability of the system. The support plays a critical role not only as a structural element but also as an integral part of the proper functioning of the robotic system. Therefore, addressing deflection issues becomes a priority in the design and optimization of these assemblies.

The analysis of proposed solutions for the deflection problem has revealed several viable strategies, each with its own advantages and disadvantages. The introduction of an anchor into the system represents an effective solution for stabilizing the support. By securing it to a more solid base, movement under load is significantly reduced, which enhances the stability and performance of the assembly. However, this solution involves significant initial costs and requires careful assessment of the long-term impact on the robotic structure. It is important to note that the installation of anchors may require periodic maintenance, incurring additional expenses, which underscores the necessity for a detailed cost-benefit analysis.

Another viable option is the integration of an elastomer into the system, which can help absorb vibrations and limit deflection. This method has the advantage of being relatively straightforward and requiring lower initial costs compared to other solutions. Elastomers are available in various degrees of rigidity, allowing for customization of the solution based on the specific needs of the support. However, it is crucial to assess the durability and potential degradation of the material over time, which may affect the efficiency of vibration absorption and, consequently, the performance of the robotic assembly.

A more radical approach, but one with potential efficiency, is the modification of the support geometry. This may involve redesigning to provide a more uniform load distribution, which could reduce deflection. Although this option may incur significant costs related to design and prototyping, a more robust design can contribute to improved stability and long-term performance of the robotic assembly. Evaluating the impact of these modifications on functionality and the interaction between components is also essential to ensure successful integration. Managing the deflection of lamp supports in the autonomous mobile platform assembly with a UV disinfection system is a critical aspect of ensuring its functionality and durability. Each proposed solution must be carefully analysed, considering not only the initial costs but also long-term sustainability, necessary maintenance, and the impact on the overall performance of the system.

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