UDC 681

LEVERAGING ADDITIVE MANUFACTURING FOR ENHANCED MINE SAFETY: A COMPARATIVE REVIEW AND EXPERIMENTAL PLAN

Marandure S. U.[1], Marandure P.[2]

[1] Avux Technologies, Harare, Zimbabwe
[2]Kwekwe Polytechnic College, Kwekwe, Zimbabwe

Abstract. This article explores using additive manufacturing (3D printing) to create rugged, custom enclosures for compact cameras in underground mining safety systems. It reviews key printing processes like Fused Filament Fabrication (FFF), Stereolithography (SLA), and Selective Laser Sintering (SLS). The research aims to improve situational awareness in the high-risk mining environment by assessing suitable printing materials and technologies to produce robust components. The study concludes by recommending an experimental plan to test the integrity and functionality of the 3D-printed enclosures to ensure they meet operational requirements.

Keywords: additive manufacturing, mining, 3D printing, surveillance, SLA, FFF and SLS.

Address for correspondence: Marandure S, 1052, Coventry Road, Gweru
e-mail: shingirai@avuxtechnologies.com

Introduction. Enhanced recording of situational analysis has become critical to the safety and operational efficiency of the innately high-risk underground mining environment. The implementation of visual evidence tools, such as cordless cameras, significantly improves post-event investigation, procedure verification and risk assessment. Hence, the need to document a first-hand narration of events that follows an individual's line-of-sight.

When incidents or accidents occur underground, post-event analysis has been subject to assumption, speculation and sometimes, inaccuracy. This is caused in some cases by loss of life, where the victim is no longer with us to narrate how an unfortunate incident occurred. In a bid to prevent reoccurrence of such regrettable circumstances, mining operations have established standards and procedures for each task. In addition to post-incident investigation, records of face operation would also assist in hazard identification, risk assessment and confirmation of compliance to set standards.

Literature Review. A review of recent literature highlights Additive Manufacturing (AM) as a transformative technology that liberates designers from traditional manufacturing constraints, enabling a focus on optimizing product function [1]. Researchers demonstrate the technical execution of this freedom by using topology optimization and Finite Element Analysis (FEA) to create lightweight yet robust lattice structures suitable for harsh environments [2]. This capability is critically applied in industries like aerospace, where metal AM achieves significant weight reduction and performance enhancement in complex components [3]. Ultimately, AM is framed not just as a production method but as a key strategic tool, offering a framework for businesses to achieve mass customization and gain a competitive advantage in rapidly changing markets [4].

Methodology. This methodology outlines the design of a rugged camera enclosure for the harsh mining environment, intended to be mounted on a miner's caplamp for a hands-free, line-of-sight perspective. The design must be highly durable, providing resistance to impact, abrasion, and ingress from dust and moisture (IP67). Additive Manufacturing (AM) is selected as the production method due to its ability to create rapid, low-cost, and customized housings that can adapt to various camera and caplamp models, a flexibility that traditional manufacturing lacks. Critical design considerations include keeping the attachment lightweight to maintain ergonomic balance, ensuring the mount is secure yet convenient for quick removal, and engineering a precise lens opening to prevent optical vignetting, thus balancing robust protection with full functionality.

Review of 3D Printing Processes. This experimental plan outlines a multi-stage process to validate the camera housing design. It begins with creating a precise digital model by 3D scanning the camera and caplamp into CAD software. An initial, low-cost prototype is then 3D printed using Fused Filament Fabrication (FFF) with PETG material to test basic fit and compatibility. Following design refinements, a final, high-fidelity prototype will be professionally printed using Selective Laser Sintering (SLS) with Nylon PA12. This robust final unit will undergo rigorous functional testing, including a water submersion test to meet IP67 ingress protection standards and a formal impact test in collaboration with the National Standards Association to confirm its ruggedness for the mining environment.

Conclusion. This study focused on polymer AM processes without taking into consideration metal 3D printing due to its cost. The proof testing procedure, particularly for IP67 intrinsic safety focuses on functionality; not exploring accreditation or certification. Future work may investigate metallic filaments, partnering accredited laboratories and onsite 3D printing for mining process components. The research suggests a manufacturing process for Proof-of-Concept ready prototypes for the mining environment. It aimed to realize the full potential of Additive Manufacturing, not only for optimal functionality but also as an effective business model for rapid prototyping in customer-centric production.

References

1. Tao, W. Design of lattice structure for additive manufacturing / W. Tao, M. C. Leu // International Symposium on Flexible Automation (ISFA). – 2016. – P. 321–326.

2. Additive Manufacturing as a strategic tool for industrial competition / F. G. Sisca [et al.] // IEEE 2nd International Forum on RTSI. – 2016. – P. 1–6.

3. Metal additive manufacturing in aerospace: A review / B. Blakey-Milner, P. Gradl, G. Snedden [et al.] // Materials & Design. – 2021. – Vol. 209. – Art. 110008.

4. Gibson, I. Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing / I. Gibson, D. Rosen, B. Stucker. – 2nd ed. – New York: Springer, 2015. – 498 p.

UDC 681

AUTONOMOUS DISINFECTION ROBOT WITH ROBOTIC ARM FOR PRECISION CLEANING

Denzel C. Ndavambi[1], Kelvin Chihota[1], Doubt Simango[1], Makusha D. T.[2]

[1]Chinhoyi University of Technology, Chinhoyi, Zimbabwe
[2]Harare Institute of Technology, Harare, Zimbabwe

Abstract. Hospital-acquired infections (HAIs) remain a major challenge to patient safety and healthcare efficiency. This project presents the design and implementation of an autonomous disinfection robot equipped with a 6-degree-of-freedom robotic arm for precision sanitization in healthcare environments. The robot integrates a LiDAR-based SLAM system for navigation, mecanum wheels for omnidirectional mobility, and an electrostatic spray system for targeted disinfection. A database-linked user interface allows authorized personnel to monitor, schedule, and control disinfection processes remotely. Simulation and prototype results confirm that the system effectively maps environments, avoids obstacles, and performs adaptive surface cleaning with minimal human intervention.

Keywords: autonomous robotics, disinfection robot, SLAM, mecanum wheels, robotic arm, hospital sanitation.

Correspondence address: Doubt Simango, Chinhoyi University of Technology
e-mail: dsimango@cut.ac.zw

Introduction. Hospital-acquired infections affect millions annually, posing serious risks to both patients and healthcare workers (CDC, 2024). Manual disinfection methods often lack consistency and fail to reach concealed surfaces. Robotics, coupled with UV-C or electrostatic disinfection, offers improved efficiency and reduced human exposure (WHO, 2020).

This project develops an autonomous robot capable of navigating hospital rooms, identifying contaminated zones, and executing targeted disinfection using an articulated robotic arm. Unlike conventional fixed-spray robots, the proposed system reaches under beds and around complex medical setups with enhanced precision.

Methodology.

1. Mechanical Design.

The mobile platform employs mecanum wheels, providing full 360° mobility for maneuvering in tight hospital spaces. A 6-DOF robotic arm, driven by Dynamixel servos, performs surface-level disinfection with accurate motion via inverse kinematics. The frame uses carbon fiber polymer for reduced weight and rigidity.

2. Sensor and Control System.

The system integrates LiDAR for obstacle detection and SLAM for real-time mapping and localization. An onboard microcontroller (Arduino Mega) manages motion planning and sensor data. A* path planning ensures optimal trajectory between rooms.

3. Disinfection System.

A diaphragm pump drives disinfectant to an electrostatic nozzle, producing uniformly charged droplets (40–80 µm) that adhere to surfaces, maximizing coverage while minimizing chemical waste.

4. Database and User Interface.

The UI allows hospital staff to log room occupancy and monitor the robot's status. The Room Status and Users tables manage disinfection scheduling and system access. Only authorized personnel can activate or halt the robot's operation, ensuring safety compliance.

Results and Discussion. Simulation and testing were performed in CoppeliaSim and MATLAB. The robot successfully generated a 3D environmental map using LiDAR and autonomously planned paths around obstacles. Inverse kinematics ensured smooth arm movement, maintaining reachability while avoiding collisions.

Trajectory control results showed minimal position and orientation errors, confirming accurate navigation. The database interface functioned effectively – automatically initiating disinfection in empty rooms and restricting access during occupancy.

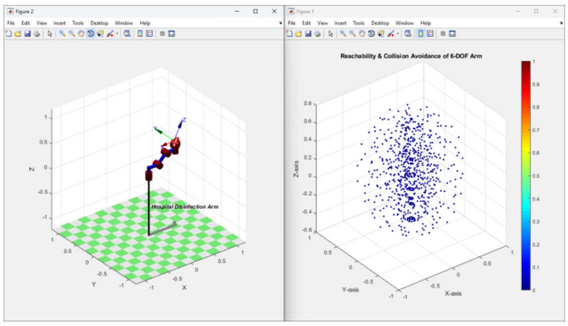

Figure 1 – Reachability and Collision Avoidance of the Robotic Arm

These outcomes demonstrate the system's potential to complement hospital cleaning operations, reduce infection transmission, and enhance sanitation efficiency through autonomous operation.