Development of a Six-Axis Robotic Arm with Embedded Control for Safe Medical Plasma Therapy in Biomedical Applications

IntelliScience INSTITUTE

IMECE 2025

Track 7: Biomedical and Biotechnology
Topic 5 : Medical Robotics, Rehabilitation, and Surgery

*Aayushya Patel, **Sohail Zaidi
*Cupertino High School, **San Jose State University

IMECE2025 Poster #175561

Introduction & Goals

Cold plasma therapy enhances wound healing due to its **antimicrobial** and **tissue-regenerative properties**. However, it **relies** on precisely **controlling plasma exposure parameters**; conditions **difficult to maintain** manually, especially on irregular wound surfaces.

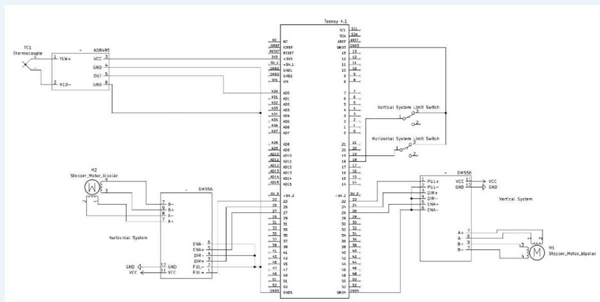
This study proposes an automated **six-axis robotic arm** that delivers safe, uniform plasma exposure over complex geometries. We integrate robotics, **embedded control**, and biomedical design into a cost-effective, modular platform enabling reproducible plasma treatment and future clinical scalability.

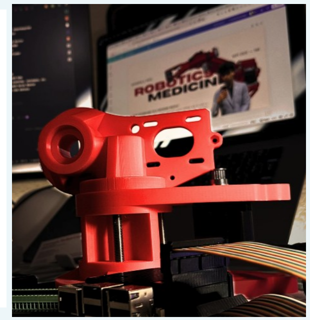
Background

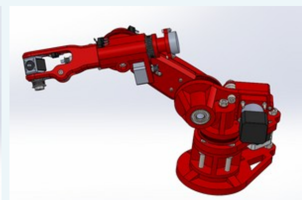
Dielectric barrier discharge (DBD) plasma is a type of cold atmospheric plasma generated between two electrodes separated by a dielectric layer, producing RONS that inactivate pathogens and stimulate cell rejuvenation at room temperature. Unlike thermal plasmas, DBD operates without significant heat, making it suitable for direct contact with tissue. Its proven antimicrobial and tissue-regenerative properties have driven interest in wound care, yet achieving controlled and uniform plasma exposure across irregular surfaces remains a major challenge—motivating robotic automation for precision delivery.

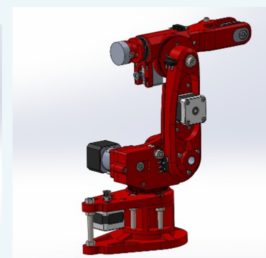
Experiential Robot Parameters

- **Mechanical Output:**
  - Max tip speed = **150 mm/s**
  - Positional resolution = 0.09mm
  - Accuracy = ±0.1 mm
- **Operational Range:**
  - Max scan radius ≈ 20 in;
  - Z max ≈ 25 in.
- **Torque Calculations:**
  - NEMA 17 stepper motors, **MAX 4.5 Nm** torque @ high load joints









Methods and Procedures

All components of the robotic arm were designed in SolidWorks and 3D printed for rapid iteration.

- **Mechanical Design:** High-torque **actuators (up to 5 Nm)** with gearboxes and mechanical stops ensure stable motion. The arm features modular joints, safety redundancies, and a scanning **volume of ~116,000 cm³.**
- **Control Architecture:** A dual-processor system—**Teensy 4.1** (**600 MHz**) for real-time motion and **Raspberry Pi 5** for trajectory planning and GUI coordination.
- **Software Tools: LinuxCNC** and **MATLAB** used for blended trajectory generation and **Jacobian Inverse Kinematics** that maintain constant orientation and standoff distance.
- **Testing:** The prototype was evaluated for positional accuracy, repeatability, and torch path stability on both flat and curved targets.

Results & Discussion

Initial experiments confirm:

- **Stable and repeatable** scanning across complex surfaces → **motor encoder feedback**
- Constant probe orientation and distance, ensuring safe exposure.
- Smooth trajectory blending without abrupt transitions.
- **Accuracy deviation < 0.1 mm** over extended paths.

Compared to manual operation, the **robotic arm provides significantly improved precision, consistency, and reproducibility**, validating its use in controlled plasma therapy. The **lightweight 3D-printed frame** maintains rigidity while improving portability and clinical adaptability.

Conclusions / Recommendations

This project demonstrates a functional **robotic prototype for controlled plasma wound treatment**, combining **mechatronics**, **control systems**, and **biomedical** design into a single platform.

Key takeaways:

- **Automated plasma delivery** improves **safety and precision.**
- **Dual-processor control** ensures both **responsiveness** and flexibility.
- The **modular design** supports future **scalability** in medical or industrial plasma applications.
- Integrate real-time sensor feedback for closed-loop control.
- Develop quantitative wound-treatment models for dose optimization.
- Conduct clinical and biological validation in collaboration with medical researchers.

Acknowledgments

- I'd like to thank **Dr. Sohail Zaidi**, professor at **SJSU** for mentorship in the making of this project
- I'd also like to thank **Manuel Espindola** for his mentorship and advice relating to robotics and engineering.

References

[1] Fridman, G. et al., Plasma Medicine: Applications of Low-Temperature Plasma in Medicine, Plasma Processes and Polymers, DOI: 10.1002/ppap.200900083.

[2] Misra, N. N. et al., Cold Plasma in Medicine and Healthcare: Applications and Mechanisms, Trends in Biotechnology, 2020.