Development of a Six-Degree-of-Freedom Robotic Platform for Automated DBD Plasma Wound Treatment

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Abstract

Dielectric Barrier Discharge (DBD) atmospheric plasma has emerged as a promising modality for wound care; however, clinical adoption remains limited due to challenges in achieving uniform plasma exposure using manual operation. This work-in-progress presents an integrated robotic platform that transforms plasma delivery into a geometry-aware, feedback-controlled process. The proposed system is a custom-designed six-degree-of-freedom robotic arm capable of holding a DBD plasma torch and scanning wound surfaces along precise tool paths. The platform consists of multiple 3D-printed (PETG) components housing six closed-loop motors and gear mechanisms to provide the required torque and motion control. Wound surface selection is achieved using a LiDAR sensor and an infrared thermal camera to generate a 2D surface map, which is converted into G-code for robotic operation. The system has been developed and tested on controlled wound surfaces, demonstrating submillimeter positional accuracy (mean error 0.027 mm, maximum 0.069 mm) over a 50 mm range. This platform is intended as a research tool to support standardization, safety validation, and future clinical adoption of intelligent plasma-based wound therapies.

Introduction

Chronic and acute wounds remain a significant global health burden, contributing to increased morbidity and mortality. In the United States alone, an estimated 10.5 million people—primarily elderly individuals and patients with diabetes—are affected by chronic wounds [1]. Despite advances in wound dressings and debridement, high rates of non-healing, infection, and recurrence persist. Chronic wounds such as diabetic and venous leg ulcers often remain in a prolonged inflammatory state, while acute surgical or traumatic wounds may experience delayed closure, infection, and scarring [2]. Conventional wound care methods, including surgical debridement, moisture-balancing dressings, and topical antibiotics, are costly and invasive. A promising non-invasive alternative involves dielectric barrier discharge (DBD) plasma jets for scanning wound surfaces. Reactive oxygen and nitrogen species (RONS) generated by plasma jets accelerate wound healing and sterilization. To enable effective treatment, an automated scanning mechanism is required and is addressed in this paper. Plasma torch development and characterization have been part of an ongoing research program at San José State University under the supervision of Dr. S. H. Zaidi.

Background

Robotic Arm for Automated DBD Plasma scanning: Academic and industrial robotic arms (e.g., Universal Robots UR series, KUKA LBR iiwa) offer high precision and programmability but lack integrated plasma-specific sensing and dosimetry hardware and frameworks. Medical robotic systems (e.g., da Vinci surgical system) prioritize sterile environments and teleoperation for invasive procedures, not surface-based plasma treatment. This gap motivated the design of a custom platform tailored to CAP wound therapy research. The design requirements for the proposed system must achieve submillimeter positional accuracy for repeatable standoff distance, provide sufficient workspace to treat typical wound areas (>200×200 mm), maintain end-effector speeds of 5–20 mm/s for controlled dose delivery, integrate real-time thermal sensing to prevent tissue damage (keeping surface <40°C), and support flexible tool path programming for irregular geometries.

Process

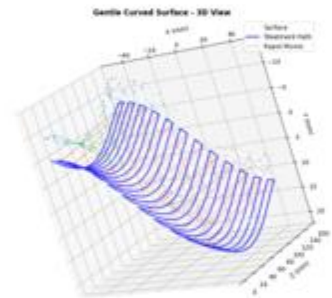

Figure I. Scan path rasterization

A serial six-degree-of-freedom manipulator was designed in Fusion360 to provide precise Cartesian positioning and wrist orientation for consistent plasma jet alignment over flat and curved surfaces within a 400 mm workspace. The system is actuated by six closed-loop NEMA 17 stepper motors with integrated encoders and 10:1–20:1 planetary gearboxes, providing sufficient torque for a 1.0 kg payload while compensating for step loss and load-induced errors. The arm structure uses PETG 3D-printed links with metal inserts at high-stress regions, with analysis showing less than 0.5 mm deflection at full payload and joint torques safely below gearbox limits, ensuring adequate safety margins. Control is managed by a Teensy 4.1 microcontroller running a 1 kHz trajectory loop with high-rate encoder feedback, using kinematic and Jacobian-based solvers. Sensor inputs from an Intel RealSense L515 LiDAR and an MLX90640 thermal camera enable smooth raster scanning over 2D and 3D surfaces, Figure I. A Raspberry Pi 5 handles trajectory uploads and data logging, while a custom DBD plasma jet is mounted on the wrist using a quick-release holder with integrated cable and gas routing to ensure safe and repeatable high-voltage plasma positioning.

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Results

Linear motion testing commanded 50 positions (0–50 mm, ~1 mm increments) measured with precision calipers. All 50 tests passed <0.1 mm criterion: mean absolute error 0.027 mm, standard deviation 0.020 mm, maximum error 0.069 mm, minimum 0.0005 mm, 100% pass rate. Table 1 summarizes key data points collected.

Table I. Robot arm performing

Test #	Expected (mm)	Measured (mm)	Error (mm)
1	0	0.017	0.017
10	9.18	9.203	0.019
20	19.39	19.338	0.049
30	29.59	29.582	0.01
40	39.8	39.803	0.007
50	50	49.938	0.062

Mean Error: 0.027 mm, Std Dev: 0.020 mm, Max: 0.069 mm

Future Work

Clinical translation requires 3D surface adaptation using depth cameras, thermal-based dose control linking plasma power, scan speed, dwell time, standoff distance, and surface temperature to prevent exceeding the 40 °C safety threshold, and validation using gelatin tissue phantoms. This work-in-progress demonstrates the integration of precision robotics, custom plasma engineering, and multimodal sensing to enable geometry-aware, feedback-controlled plasma wound therapy. The achieved submillimeter accuracy and robust hardware provide a foundation for closed-loop plasma dosimetry, with future work focusing on advanced 3D adaptation and real-time thermal feedback.

[1] C. K. Sen, “Human Wound and Its Burden: Updated 2022 Compendium of Estimates,” *Adv. Wound Care*, vol. 12, no. 12, pp. 657–670, Dec. 2023.

[2] R. G. Frykberg and J. Banks, “Challenges in the Treatment of Chronic Wounds,” *Adv. Wound Care*, vol. 4, no. 9, pp. 560–582, Sep. 2015.