Conditional Generation of Plasma Flames Using Deep Generative Models

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Plasma technologies, particularly high-temperature plasmas, offer a promising pathway toward achieving climate goal of providing CO_2-neutral high-temperature heat for industrial processes. These systems are operated entirely electrically and various gases, including air, nitrogen, or carbon dioxide, can be used as working gases. This positions plasma technologies as strong candidates for generating clean energy for energy-intensive sectors. However, the complex dynamics of plasma flames present significant challenges in optimizing these systems and understanding of flame characteristics, which is crucial for enhancing the efficiency and effectiveness of plasma-based technologies. Experimental measurements under broad operating conditions including varying electrical power, gas compositions, and flow configurations remains both financially and logistically challenging. Moreover, traditional image processing techniques are limited in their ability to capture the complex and dynamic characteristics of plasma flames. To address these limitations, this study introduces a Conditional Generative Adversarial Networks (CGANs) designed to synthesize high-resolution plasma flame images conditioned on key operating parameters: power, gas type, tangential flow rate, and axial flow rate. An experimentally measured dataset of plasma flames under various operating conditions was used to train the model. The architecture of CGAN learns the complex mapping between operating conditions and the corresponding flame images. Once trained, the model can generate realistic flame images, including those for unseen scenarios. This generative approach reduces dependency on expensive experimentation by enabling the generation of synthetic data, hence enhancing control and optimization of plasma-based combustion systems. The results demonstrate the potential of conditional GANs as a powerful tool for advancing AI-driven methodologies in combustion sciences.