Abstract

The rapidly increasing demand for sustainable and efficient agricultural practices has developed the necessity for automation in crop health monitoring, precise pesticide application, and others. However, the implementation of fully autonomous robotic systems in practical agricultural settings remains constrained by several challenges, such as uneven terrain, navigation errors, limited reach, and the extensive operational footprints of traditional agricultural robots. The proposed work addresses these issues by developing a compact and autonomous, tracked mobile manipulator that can spray pesticides and fertilizers in agricultural fields having non-uniform terrain conditions. The robotic system proposed in this work integrates a tracked vehicle platform, a serial manipulator, and a modular spraying unit with multi-pesticide carrying capability, which allows for targeted and uniform spraying, while avoiding excess pesticide use and environmental harm. The research focuses on systematic design conceptualization, hardware development, and mathematical modelling of the robotic system to facilitate robust, autonomous operation. A primary emphasis of this research is the precise navigation and trajectory tracking control of the tracked vehicle, which is essential for optimal spraying efficacy in dynamic agricultural settings that are influenced by terrain-induced disturbances, track slips, and modelling uncertainties. To address these issues, various dynamic model-based control strategies are developed and comparatively evaluated, including conventional PID control, modified model-based PID control, sliding mode control, non-integral sliding mode control, and fuzzy logic–assisted sliding mode control with genetic algorithm–based gain optimization. The efficacy of the proposed control methodologies has been verified through extensive simulation studies and experimental investigations in both structured and unstructured environments. This results in enhanced trajectory tracking accuracy, improved resistance to disturbances, and superior control performance through advanced control techniques. The outcomes of this research contribute toward advancing

autonomous agricultural robotics by providing a practical, efficient, and scalable solution for safe and precise crop management and, thereby, bridging the gap between traditional farming practices and modern autonomous robotic technologies for the same.

Keywords: Tracked mobile robot; Agricultural applications; Pesticide spraying; Dynamic modelling; GA-based gain optimization; Sliding mode control; Fuzzy sliding mode control; Trajectory tracking.