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Design of an Innovative Spraying System for High Precision Aerial Dispersion in Vineyards

By

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In the past decade, the fusion of emerging technologies such as the Internet of Things, Artificial Intelligence, and Big Data has led our society toward Industry 4.0. This movement, combined with the global importance given to the relationship between food security and quality, gave birth to the fourth agricultural revolution, which focuses on intelligent mechanization and environmental sustainability objectives. In this context, the growth in the use of autonomous Unmanned Aircraft Systems (UASs) plays an important role, particularly in precision agriculture. These systems facilitate precise field monitoring, targeted spray application with variable rates, and optimized guidance algorithms, regardless of the terrain's characteristics.

The following thesis aims to provide a comprehensive overview of the current state of the research on drones in agriculture, with a particular focus on a specific application: precision aerial spraying of pesticides in vineyards. Nowadays, the selection of a scenario that involves the application of 3D crop spray represents one of the most stimulating challenges in order to maximize canopy deposition and minimize off-target losses. The problem of drift, which has been extensively studied in conventional machines and more recently in drones, is investigated in detail to identify its causes and implement adjustments to reduce it, both in the design of the spray system and in the choice of operating parameters. For this reason, experimental campaigns to define the design of an agricultural drone for spray application are necessary, equipped with a customized spraying system, and to develop a guidance algorithm that takes into account the mission constraints.

The initial phase of the study involves wind tunnel testing to assess the spray characteristics based on different operational parameters, such as the position of the nozzles (which, as far as we know, is not investigated in the scientific literature), their type, and the pressure exerted on the liquid. In particular, the interaction between the rotor wake and the spray is analyzed. By processing the images obtained from the wind tunnel tests, a qualitative analysis of the backlit spray is performed and criteria are established for planning subsequent field trials. The field tests are conducted to determine the optimal flight mode and speed, as well as the type of nozzles to use,

by evaluating deposition on the plant at different heights and depths using various collectors, along with the amount of loss on the ground. Based on the results of these tests, a list of technical and mission requirements is compiled.

Thus, a hexacopter is designed with a Maximum Take-Off Weight (MTOW) limit of 25kg in accordance with ESA regulations for the *open category*, i.e. for low-risk operations. After developing the first prototype of the spray system used in the experimental campaigns with the DJI Matrice 600, a final spray system is defined, focusing on the design of the tank to minimize the sloshing effect. The proposed strategy involves inserting plates in the tank at suitable positions and perforating them. Moreover, fluid dynamic simulations are carried out to evaluate forces and moments generated by the movement of the liquid, which is included in the simulation model as a disturbance. The geometry of the assembly and its inertia are taken into account to simulate the dynamics of the hexacopter using MATLAB/Simulink software to follow specific paths. The control system implemented employs a traditional Proportional, Integrative, and Derivative (PID) controller. It ensures a satisfactory level of robustness in both the introduction of disturbances and the variation in liquid mass in the tank during operations.

Once the dynamics and control system have been tested, the focus shifts toward implementing various path-planning strategies. These include a simple snake trajectory for linear vineyard missions, as well as the Traveling Salesman algorithm that minimizes the path to be followed in case of individual plant interventions. In both cases, the offline generated trajectory incorporates the Theta* algorithm, which enables avoidance of obstacles previously placed on the map. Since wind and gusts significantly impact the deposition of spray droplets, these algorithms are adapted by taking into account the ground deposition of the spray, which is evaluated by considering the wind displacement through a Lagrangian particle model obtained by characterizing HCI8002 nozzle manufactured by ARAG Group.

Lastly, a novel approach of integrating PID control into a Computational Fluid Dynamics (CFD) simulation of a hexacopter is tested to achieve drone control by providing the required rotor speeds for maintaining a constant flight speed. In addition with a spray model, droplet deposition in a virtual vineyard can be evaluated.