Design of a Plant Protection Unmanned Aerial Vehicle Ultrasonic Atomizing System

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Abstract: In order to reduce energy consumption of the plant protection unmanned aerial vehicle (UAV) atomizing system and achieve a good atomizing effect, in this paper, a plant protection UAV atomizing system based on the principle of ultrasonic atomizing has been designed. The system consists of a pesticide tank, a liquid level controller, an atomizing tank, an atomizer, a fan, a spray pipe and a mounting plate. Virtual design is realized with SolidWorks to obtain a 3D model. The interference checking of SolidWorks proves no involvement existing between the parts. The finite element analysis function of SolidWorks is used to perform a finite element analysis on the mounting plate to optimize the structure. The fluid analysis function of SolidWorks is then used to verify the atomizing effect. Simulation analysis has been made to verify reliability of the design. The prototype test results show that the system has lower energy consumption but better quality than that of the pressure atomizing system. It features a simple structure, low production cost, easy maintenance, low failure rate, safety and reliability and thus will be easy to be promoted in the plant protection UAV field.

1. Introduction

In the process of plant growth, prevention and control of diseases and insect pests is critical to ensure smooth growth of plants and increase yield. It has become inevitable for promoting stable agricultural production to accelerate the mechanization level of pesticide application equipment, improve the application technology, and strengthen the ability to control pests and diseases. [1] The low utilization rate of pesticides is one of the important reasons affecting the agricultural ecological environment and quality and safety of agricultural products. Thus optimizing the pesticide spraying technology is an effective way to solve agricultural environmental pollution and improve the utilization rate of pesticides. [2] As a precise, safe and efficient operation mode emerging in recent years, UAV plant protection carries out precise pesticide application on large-scale plants through equipping a spray device on the UAV platform, which is controlled by sensors and flight control systems. [3] The plant protection UAV is based on a multi-rotor or single-rotor UAV, and equipped with a variable application device, thereby to achieve efficient and ultra-low dosage application. Compared with manual pesticide sprayers and self-propelled plant protection devices, its operating efficiency and control effect have been greatly improved. [4] In recent years, its rapid development and application has aroused widespread attention [5,6]. With rise of UAV application in agriculture, development and promotion of the plant protection UAV application technology are being conducted nationwide. [7] In China, plant protection UAVs have developed rapidly and are used in more and more plants. [8] Most of the plant protection UAVs do not require a special airport for takeoff and landing, and have high flight stability, good handling performance, and flexible operation. [9] UAV plant protection has overcome disadvantages of traditional spraying methods, produced low operating costs but better prevention and control effects. Its efficiency is three times that of ground

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machinery and 30 times that of labor. [10] Plant protection UAVs are superior in fast operation speed, high spraying efficiency, and strong ability to respond to sudden disasters. They can work in the field, which is beyond the reach of agricultural machinery or human [11], and also boast higher safety. [12] Accordingly, they gradually become the preferred spraying operation method, and their development prospect is highly valued in the field of agricultural plant protection. Continuous improvement of small UAVs and their flight control technology has promoted research and development and practical application of aviation plant protection technologies. Small UAVs are characterized by high efficiency, good effect, strong 3D nature, no damage to plants, low labor intensity, high flexibility and convenience, preciseness and labor-saving. Especially they can adapt to complex terrains such as hills and mountains and spraying operations in places inaccessible by machinery. [13] Agricultural UAVs have flexible take-off and landing operations, high operating efficiency, good control effect, and obvious economic benefits. They can save resources, protect environment and are widely applicable to agricultural areas hardly accessed by ground machinery. Obviously, they have shown their uniqueness and advantages in practical application. [14]

The atomizing system is the core part of the plant protection UAV. Due to the limitation of the UAV power supply capacity, the atomizing system must have as low energy consumption as possible while achieve favorable atomizing effect. In this paper, the principle of ultrasonic atomizing has been employed to achieve atomization of pesticide liquids, requiring less energy than general pressure atomizing. In addition, the atomic droplets are below 50μm, indicating better atomizing quality than that of ordinary pressure atomizing. Besides, the ultrasonic atomizing system also has strength in simple structure, low production cost, easy maintenance, low failure rate, safety and reliability, and thus is easy to be promoted in the field of plant protection UAV.

2. Overall Design and Working Process

The ultrasonic atomizing system consists of a pesticide tank, a liquid level controller, an atomizing tank, an atomizer, a fan, a spray pipe, and a mounting plate. The pesticide tank is designed for storing the pesticide liquid, the liquid level controller for controlling the amount of pesticide liquid in the atomizing tank, the atomizing tank for holding the pesticide liquid for atomizing, the atomizer for atomizing pesticide liquid, the fan for transporting the atomized pesticide liquid to the spray pipe, the spray pipe for transporting the atomized pesticide liquid to the outlet and the mounting plate for mounting the entire atomizing system to the bottom of the UAV.

The system works like this: pesticide liquid is first added to the pesticide tank and automatically flows into the atomizing tank under the action of gravity. When the pesticide liquid in the atomizing tank reaches the position defined by the liquid level controller, it stops flowing under control of the liquid level controller. Then, the UAV will take off and arrive at the designated place for plant protection. The remote control command is sent to activate the atomizer and turn on the fan, so that pesticide liquid in the atomizing tank is atomized and transported along the spray pipe and finally ejected from the outlet. Under the action of the downward air flow generated by the UAV wings, the atomized pesticide liquid is sprayed to the target plants. As the spray progresses, the pesticide liquid in the atomizing tank will decreases and flows to atomizing tank under gravity when the liquid level is lower than the position defined by the liquid level controller, so that the pesticide liquid level in the atomizing tank can be maintained the same during the spray process. The working process is shown in Fig. 1.

3. Design of the Atomizing System

3.1 Design of the Pesticide Tank

The pesticide tank (Fig. 2) is flat cylindrical and made of engineering plastics, with the volume of 5L. On the upper side, it has a feeding port, which is equipped with a filter to prevent impurities in the pesticide liquid from entering the pesticide tank. The outside of the feeding port is connected with a pesticide tank cover through threads. On the pesticide tank cover is an air vent that maintains the pressure of the pesticide liquid in the pesticide tank to be the atmospheric pressure and avoids negative pressure due to outflow of the pesticide liquid. At the bottom of the pesticide tank is the pesticide outlet, which is connected to the liquid level controller through threads. The lower part of the pesticide tank has mounting holes for connection to the mounting plate.

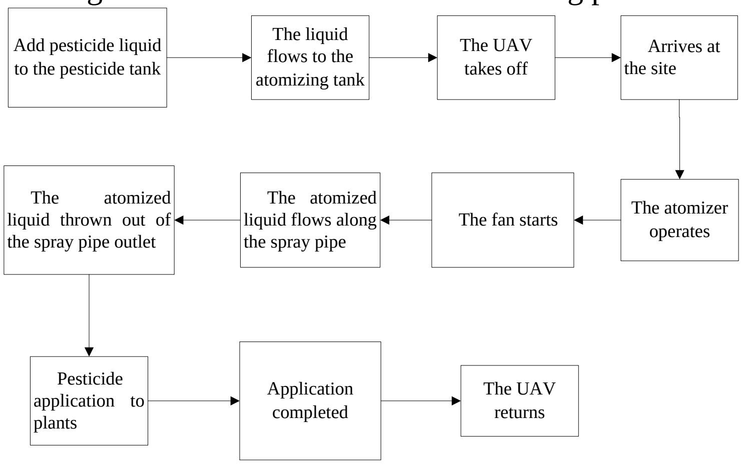

Figure 1. Working process

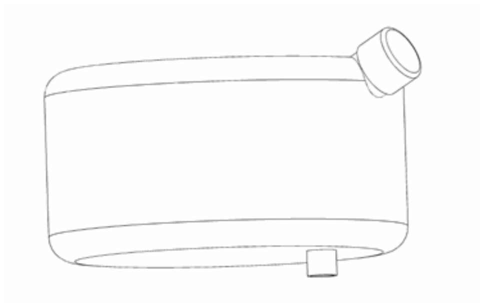

Figure 2. Pesticide tank

3.2 Design of the Liquid Level Controller

The liquid level controller applies a mechanical float liquid level controller and is composed of a float chamber, a float, a needle valve, and housing. The upper part of the housing has threads to connect the pesticide outlet of the pesticide tank. The lower part of the housing also has threads for connection to the pesticide inlet of the atomizing tank. Inside the housing is a float, which can rise or fall according to the liquid surface. Above the float is a needle valve that controls the liquid level controller to open or close the pesticide inlet. When the liquid level in the atomizing tank is lowered, both the float and the needle valve are lowered, to open the pesticide inlet, so that the pesticide liquid in the pesticide tank flows into the atomizing tank through the inlet. When the liquid level in the atomizing tank rises, the float also rises and drives the needle valve to a certain level to close the pesticide inlet. Thus, the liquid level in the atomizing tank can be controlled. The liquid level controller here is mechanical, requires no power supply, and has a simple structure and reliable operation.

3.3 Design of the Atomizing Tank

The atomizing tank (Fig. 3) is a flat, square cylindrical closed structure mounted under the mounting plate. The atomizing tank is installed under the pesticide tank. The upper part of the atomizing tank has a pesticide inlet, which is connected to the liquid level controller through threads. The atomizing tank has mounting holes on the upper side for fan and spray pipe installation. The atomizing tank has a groove at the bottom for the atomizer.

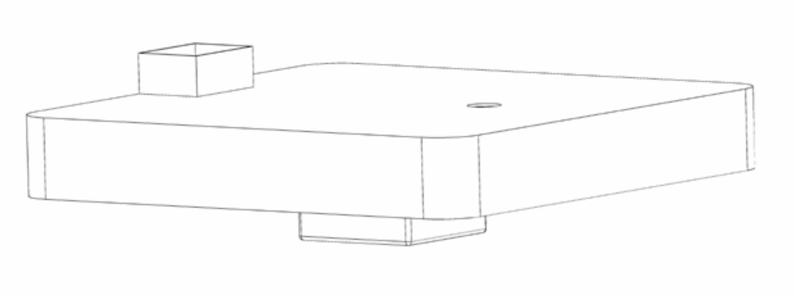

Figure 3. Atomizing tank

3.4 Selection of the Atomizer

The atomizer applies an ultrasonic atomizer. Ultrasonic atomizing utilizes high-frequency oscillations of electrons and breaks up the molecular bonds between liquid water molecules through the high-frequency resonance of ceramic atomization pieces, thus to generate water mist. Different from pressure atomizing, ultrasonic atomizer atomizing does not need to pressurize the pesticide liquid and produces droplets smaller than DN 50μm, which is more conducive to long-distance transport of the atomizing pesticide liquid. In this design, an ultrasonic atomizer with dry-run protection function is selected and can automatically power off when the pesticide liquid in the atomizing tank runs out.

3.5 Selection of the Fan

In this design, the axial flow fan is selected and installed in the spray outlet of the atomizing tank and powered by UAV power supply. During work, the pesticide liquid droplet generated in the atomizing tank is accelerated to the spray pipe.

3.6 Design of the Spray Pipe

The spray pipe (Fig. 4) is made of PVC pipes, with the inlet connected to the atomizing tank. There are four outlets located under the UAV rotor. When the atomized pesticide liquid in the atomizing tank is sprayed along the outlet, it is sprayed on the plants under the action of the downdraft generated by the UAV wings.

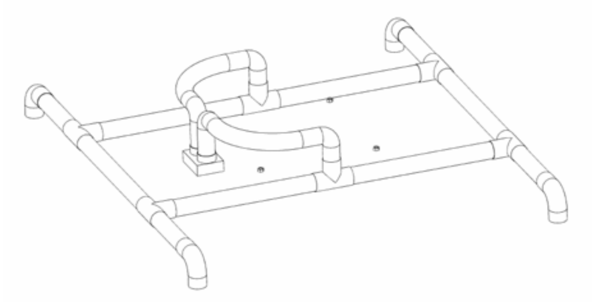

Figure 4. Spray pipe

3.7 Design of the Mounting Plate

The ring on the upper part of the mounting plate (Fig. 5) is used to limit the pesticide tank and is bolted to the through hole in the lower part of the pesticide tank. There are four shoulders in the upper part of the ring, having through holes bolted to the bottom plate of the UAV. There are grooves on the lower part of the mounting plate for mounting the atomizing tank, which is inserted from one side and then fixed by the baffle. The spray pipe is fixed by the snap ring on the mounting plate.

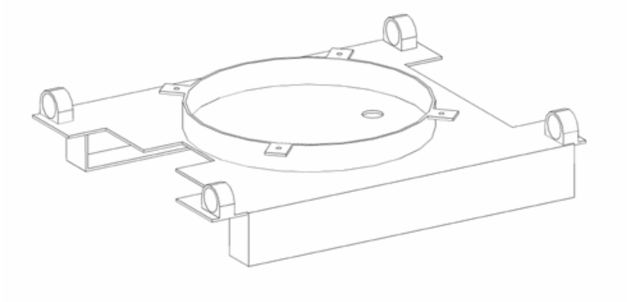

Figure 5. Mounting plate

4. Simulation Analysis

After completion of design of the parts, the assembly function of the SolidWorks is used to virtually assemble the parts to form a 3D model (Fig. 6). SolidWorks interference checking function is utilized to ensure no interference between parts. Then its fluid analysis function is applied to verify the effect of atomizing. The verification shows that there is no interference between the parts, and the pesticide liquid can be well atomized. Using the finite element analysis function provided by SolidWorks, the finite element analysis of the mounting plate is performed to optimize the structure. The installation effect of the ultrasonic atomizing system installed on the plant protection UAV is shown in Fig. 7.

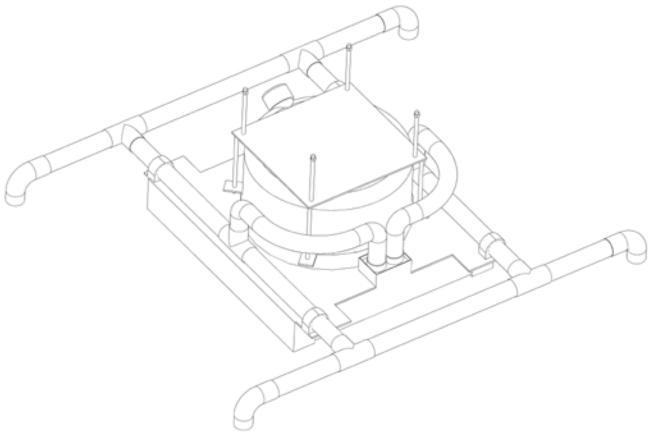

Figure 6. Ultrasonic atomizing system

Figure 7. Installation effect

5. Conclusion

In this paper, a plant protection UAV atomizing system has been designed with the ultrasonic atomizing principle to atomize pesticide liquid. The system is consisted of a pesticide tank, a liquid level controller, an atomizing tank, an atomizer, a fan, a spray pipe, and a mounting plate.

Virtual design is realized with SolidWorks to obtain a 3D model. The interference checking of SolidWorks proves no involvement existing between the parts. The finite element analysis function of SolidWorks is used to perform a finite element analysis on the mounting plate to optimize the structure. The fluid analysis function of SolidWorks is then used to verify the atomizing effect. Simulation analysis has been made to verify reliability of the design.

The prototype test results show that the system has lower energy consumption but better quality than that of the pressure atomizing system. It features a simple structure, low production cost, easy maintenance, low failure rate, safety and reliability and thus will be easy to be promoted in the plant protection UAV field.

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References

[1] Lou Shangyi, Xue Xinyu, Gu Wei, Cui Longfei, Zhou Qingqing, Wang Xin, Current Status and Trends of Agricultural Plant Protection Unmanned Aerial Vehicle[J]. Journal of Agricultural Mechanization Research, 2017, 39(12): 1-6+31.
[2] He Yong, Xiao Shupei, Fang Hui, Dong Tao, Tang Yu, Nie Pengcheng, Wu Jianjian, Luo Shaoming, Development situation and spraying decision of spray nozzle for plant protection UAV[J]. Transactions of the Chinese Society of Agricultural Engineering, 2018, 34(13): 113-124.
[3] Chen Ji, Liu Weihua, Yuan Yiming, Application and development trend of nozzles on UAV[J]. China Plant Protection, 2018, 38(03): 66-70.
[4] Zhou Le, Li Ting, Zhou Yongxin, Application of Online Mixing Pest Technology in Plant Protection UAV[J]. Mechanical Engineer, 2019, (06): 7-9.
[5] Zhu H, Lan Y B, Wu W F, et al, Development of a PWM precision spraying controller for unmanned aerial vehicles[J]. Journal of Bionic Engineering, 2010, 7(3): 276-283.
[6] Bae Y, Koo Y M, Flight attitudes and spray patterns of a rollbalanced agricultural unmanned helicopter[J]. Applied Engineering in Agriculture, 2013, 29 (5): 675-682.
[7] Xu Xiaojie, Chen Shengde, Zhou Zhiyan, Lan Yubin, Luo Xiwen, Analysis and Thinking of Evaluation Methods About the Main Performance Indexes of Plant Protection UAV[J]. Journal of Agricultural Mechanization Research, 2018, 40(12): 1-10.
[8] Yuan Huizhu, Xue Xinyu, Yan Xiaojing, Qin Weicai, Kong Xiao, Zhou Yangyang, Wang Ming, Gao Saichao, Applications and prospects in the unmanned aerial system for low-altitude and low-volume spray in plant protection[J]. Plant Protection, 2018, 44(05): 152-158+180.
[9] Hu Caiqi, Shao Minghe, Wang Cunpeng, Chen Dawei, Lan Yubin, Wang Zhengtian, Design and Experiment Research of Spraying Multi-rotor UAV[J]. Journal of Agricultural Mechanization Research, 2018, 41(03): 118-123.
[10] Cunha J, Farnese A C, Olivet J J, et al, Spray deposition on soybean plant in aerial and ground application[J]. Engenharia Agricola, 2011, 31 (2): 343-351.
[11] Zhang Dongyan, Lan Yubin, Chen Liping, Wang Xiu, Liang Dong, Current Status and Future Trends of Agricultural Aerial Spraying Technology in China[J]. Transactions of the Chinese Society for Agricultural Machinery, 2014, 45(10): 53-59.
[12] Yang Luqiang, Guo Lin, Zhu Jiafan, Gao Zhichao, Zhou Tiquan, Yu Zirong, Peng Jiwen, Zhang

Rukun, The Development Situation and Prospect of Agricultural UAV in China[J]. Journal of Agricultural Mechanization Research, 2017, 39(08): 6-11.
[13] Zhang Pan, Lv Qiang, Yi Shilai, Liu Ying, He Shaolan, Xie Rangjin, Zheng Yongqiang, Pan Haiyang, Deng Lie, Evaluation of spraying effect using small unmanned aerial vehicle(UAV) in citrus orchard[J]. Journal of Fruit Science, 2016, 33(01): 34-42.
[14] Lan Yubin, Wang Linlin, Zhang Yali, Application and prospect on obstacle avoidance technology for agricultural UAV[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2018, 34(9):104-113.