Journal of Artificial Intelligence Practice (2025)
Clausius Scientific Press, Canada
DOI: 10.23977/jaip.2025.080101
ISSN 2371-8412 Vol. 8 Num. 1

Design of Multi-functional Agricultural Management Robot Based on Machine Vision

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Keywords: Field Management, Robots, Visual Recognition

Abstract: In response to the relevant policies for agricultural development in China, our team has designed and produced a multifunctional agricultural management robot based on STM32, aiming to achieve intelligent farmland management. The robot adopts remote control mode, combined with modeling and automatic control system, integrating functions such as crop pest control, pesticide spraying, and fertilization. The overall structure of the robot includes a motion chassis, a pesticide spraying mechanism, and a remote control sensing module. Through precise cooperation, each module achieves an intelligent integrated process of pest control, pesticide spraying, and fertilization. In terms of specific design, the sports chassis is responsible for movement and positioning, the pesticide spraying mechanism can accurately control the spraying of drugs, the storage mechanism is used to store fertilizers and pesticides, and the remote control module provides real-time monitoring and operation functions. The experimental results show that the robot can effectively improve the efficiency of agricultural management, reduce labor costs, and provide reliable technical support for the development of modern agriculture.

1. Introduction

Developing modern agriculture is an important component of China's modernization[1], it is an objective need to comprehensively improve the level of agricultural productivity in China, accelerate the process of industrialization and urbanization, and solve the "three rural issues"[2]. Agricultural machinery technology is rapidly developing, and machines can be seen in every aspect from planting, fertilizing, weeding to harvesting. This not only greatly improves production efficiency, but also reduces labor costs.

In response to the current development status and market demand of agricultural management robots in China, our designed solution can effectively improve agricultural problems caused by the loss of rural labor force, low production efficiency, and unstable production quality. The research significance of our proposed multifunctional field management robot is not only reflected in improving agricultural production efficiency and sustainable development capabilities, but also in promoting the development of agriculture towards intelligence, refinement and greening.

In China, with the acceleration of agricultural modernization, the research and development of agricultural management robots have gradually received attention. Domestic agricultural robots are mainly focused on functions such as unmanned aerial vehicle spraying, farmland inspection, and environmental monitoring, and are still in the stage of continuous optimization and improvement.

Foreign countries started early in agricultural robot technology, mainly applied in fields such as unmanned aerial vehicle spraying, intelligent irrigation, and crop monitoring[3].For example, some research institutions and companies in the United States and Europe have developed automated spraying systems for specific crops, using sensing technology and robotic arms to achieve precise fertilization and pest control. These robots typically integrate advanced sensors and image processing technology to monitor crop growth in real-time and perform automated operations based on demand. However, despite significant progress in the field of agricultural robots both domestically and internationally, there are still some challenges that need to be addressed Agricultural robots still need to further improve their level of intelligence and automation to meet the increasingly complex demands of agricultural production.

The multifunctional agricultural management robot designed by our group is mainly designed with hardware design and functional design as the main directions. The design framework is shown in Figure 1.

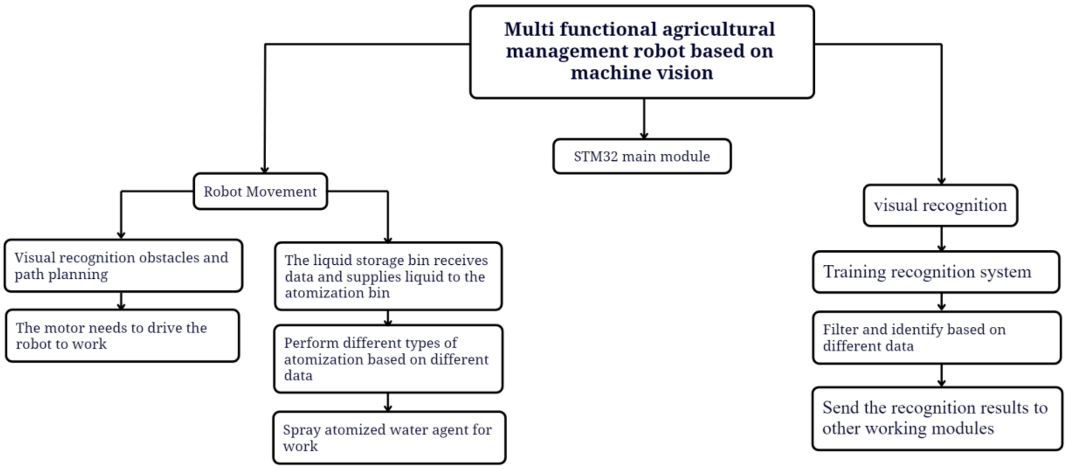

Figure 1: Overall System Framework Diagram

2. Hardware Design

Multi-functional agricultural management robots can complete multiple tasks in agricultural production, such as fertilization, irrigation, weeding, pest control, etc., by integrating advanced robot technology, sensing technology, etc. The research on this technology covers multiple fields, including robot design, intelligent control and optimization, environmental perception, and data analysis. For the application of medicine to a plant or a plant in a certain state, the unmanned precision spray truck is flexible, and the identification efficiency is high, which can effectively and quickly solve the problems such as insufficient mechanization in some areas[4].

2.1 Hardware design

The core of a multifunctional agricultural management robot is its hardware system, including mechanical structure, sensors, actuators, and power system. In order to achieve multitasking in field management, robots need to have strong comprehensive capabilities. The research on hardware design mainly focuses on the following aspects.

Mechanical structure design: Agricultural management robots typically need to cope with complex field environments, including but not limited to muddy and irregularly undulating soil in agricultural work environments, and various agricultural planting environments with different terrains. Therefore, their mechanical structures must have strong adaptability and flexibility, such as ensuring their ability to move under different soil conditions and adapt to uneven terrains such as slopes and mud. Meanwhile, the mechanical structure needs to ensure the stability and efficiency of the robot during operation.

Multi-functional actuators: In order to complete tasks such as weeding and fertilizing, robots must be equipped with different actuators, such as sprayers. These actuators need to automatically switch according to job requirements to achieve multi use on one machine.

2.2 Atomization spray

The atomized liquid can have a greater impact on the plants themselves, and firstly, atomized spraying can significantly improve water utilization efficiency. By refining water droplets and atomizing spraying, it is possible to ensure that water is more evenly distributed on the surface of crops, reducing water loss and evaporation, thereby improving irrigation efficiency. This not only helps crops better absorb water and nutrients, but also reduces irrigation costs.

Secondly, atomized spraying helps regulate the growth environment of crops. During the agricultural planting season, atomized spraying can reduce the heat pressure on crops and improve their adaptability and immunity by increasing air humidity and lowering temperature. Simultaneous atomization spraying can reduce the occurrence of pests and diseases.

In addition, atomized spraying also has advantages in the application of pesticides and fertilizers. Through atomized spraying, pesticides and fertilizers can adhere more evenly to the surface of crops, improving application efficiency and reducing waste of drugs and fertilizers. This not only helps to reduce agricultural production costs, but also reduces environmental pollution.

The agricultural management robot designed by our group uses a water pump to supply tap water, liquid fertilizers, liquid pesticides, etc. into the atomization chamber. There are three identical atomizers placed in the atomization chamber, with a voltage of 100Vac, a frequency of 60Hz, and a water consumption of 800mL per kilogram. The diameter of the atomization chamber is 240mm, and the water storage depth is 40mm.The engineering drawing of the atomization chamber is shown in Figure 2 and Figure 3.

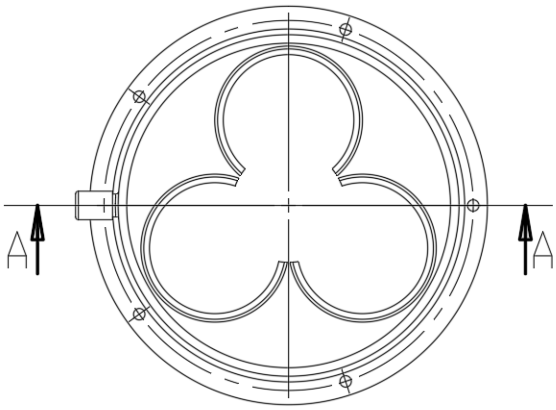

Figure 2: Atomization chamber model

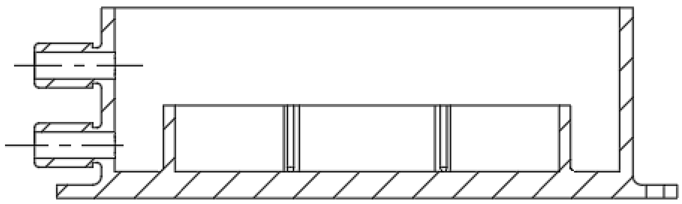

Figure 3: Sectional view of atomization chamber

If the water atomization amount per kilogram is 700mL, the amount of water that can be accommodated in the atomization chamber is:

$$V = \pi r^2 h = \pi\left(\frac{d}{2}\right)^2 h \tag{1}$$

Among them, V is the volume of water (unit: mm3), D is the storage diameter of the atomization chamber (unit: mm), and H is the storage depth (unit: mm)

The water quality is:

$$m = V \times \rho \tag{2}$$

Among them, is the water density (unit: kg/m3)

The total atomization amount is:

$$Q = m \times 800\, mL/kg = 1.106\, L/min \tag{3}$$

Atomizing agents are sprayed onto crops through nozzles in the form of small water droplets, which are more easily absorbed by the leaves of the crops, thereby increasing their water absorption and nutrient uptake. This is crucial for the growth and development of crops, helping to improve their yield and quality. Significantly reduce water usage and achieve water-saving benefits. The use of tubular spray atomizing agent spraying technology is suitable for a variety of crops and growth environments. Both field crops and vegetables can achieve better growth results through atomized spraying. At the same time, the atomization water spraying technology is also applicable to different climatic conditions and soil types, with strong adaptability and flexibility. Using a nozzle to spray atomized water can greatly improve work efficiency. Compared to traditional artificial irrigation methods, atomized spraying is faster and more convenient, and can significantly reduce labor intensity. The engineering drawing of the atomizing nozzle is shown in Figure 4. The comparison between simultaneous atomization spraying and manual spraying is shown in Table 1 and Table 2.

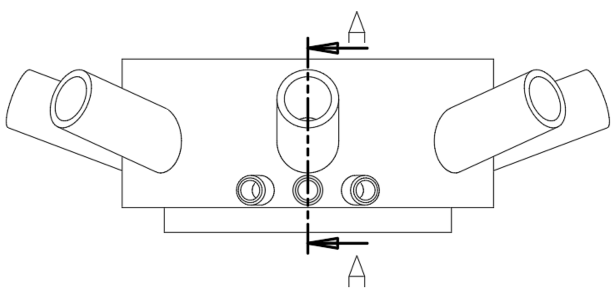

Figure 4: Design scheme of atomizing nozzle

Table 1: Comparison between Atomization Spray and Artificial Agricultural Water Agent[5] Spray

Compare projects	Atomizing nozzle spraying	Manual spraying
Operation altitude	Near the water spraying area of crops that require water	0.1-0.4m above the crops
Operation perspective	Tilt 45°	Vertical to crops
Operation time	Long term battery life	-
Operation speed	0~15km/h	-
Operation safety	No contact with farmers, no harm to manual labor	May harm the health of farmers
Operation accuracy	Visual recognition, positioning cruise, high accuracy	Cannot guarantee even and accurate spraying
Operation factors affecting	Rain and snow have an impact on visual recognition	Considering the health status of farmers, continuous and accurate operations cannot be guaranteed
Operation cost	Low equipment cost and low maintenance cost	High labor costs
Operation requirements	Automatically recognize work without the need for manual intervention	Training is required for agricultural personnel

Table 2: Comparison of Atomization Spraying Efficiency and Artificial Pesticide Spraying Efficiency

Compare projects	Atomization spray	Manual spraying
Operation time	30min	30min
Operation range	4 acres	1.3 acres
Operation cost	12 yuan/h	25 yuan/h
Operation result	An average of 8 insecticides per acre	An average of 5 insecticides per acre
Operation efficiency	Significant improvement compared to manual labor	-

From the above chart, it can be seen that the spraying operation of water agent atomization through the atomizing nozzle has better operational efficiency compared to traditional agricultural manual spraying, and can achieve more accurate agricultural operations.

2.3 Robot Traveling Mechanism

The robot designed in this article is mainly applied in agricultural scenes, with a designed full load weight of 30kg and a maximum climbing angle of 30°.

Therefore, firstly, the driving analysis of the mobile robot on a 30° slope is carried out to determine the maximum torque and maximum power that its driving motor[6] needs to achieve.

Since the mobile robot is driven by four wheels together[7], for the convenience of analysis, it is assumed that each wheel is uniformly distributed by the gravity of the small car, and the farmland environment is complex. Assuming that the friction coefficient of the bottom of the farmland is the same, the frictional resistance experienced by each wheel is equal, and the driving force provided by each wheel is equal. In the analysis process, only the force on one driving wheel of the robot chassis needs to be analyzed to determine the performance requirements of the driving wheel of the mobile robot. The force analysis of the robot driving on a 30° slope is carried out, and the force diagram is shown in Figure 5.

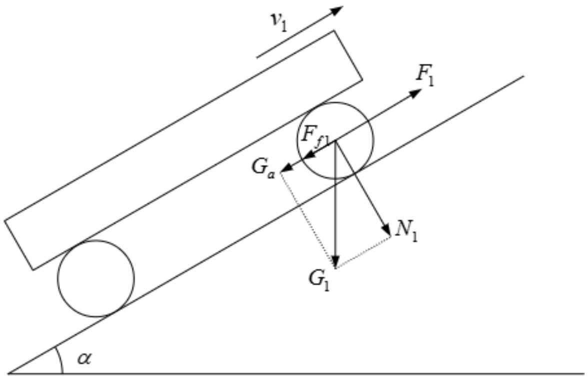

Figure 5: Force analysis diagram under the slope

Among them, α is the slope angle, and this article designs a value of 30 °; G_1 represents the sum of the weight of the driving wheel itself and the partial weight of the mobile robot body it bears, which can be analyzed as one-quarter of the full load; G_α represents the force component of gravity borne by the driving wheels in the direction of the sloping road surface; N_1 represents the force component of the driving wheel perpendicular to the slope direction, that is, the pressure on the farmland; F_{f1} represents the frictional force acting on the driving wheels in the direction of the sloping road surface; F_1 represents the traction force of the driving wheels that allow the car to remain stationary on a slope.

So in order for the mobile robot to remain stationary on a slope, it is necessary to achieve force balance in the slope direction, that is, the traction force of the wheels should be equal to the sum of the frictional force in the slope direction and the gravitational component in the slope direction.

During the motion, the pressure exerted by the driving wheel perpendicular to the slope direction is

$$\mathrm{N}_1 = \mathrm{G}_1 \times \cos\alpha \tag{4}$$

The frictional force acting on the driving wheel at this time is

$$F_{f1} = f_1 \times N_1 \tag{5}$$

Among them, f_1 represents the rolling friction coefficient between the driving wheel and the bottom of the farmland.

Therefore, the force component of the vehicle's gravity borne by the driving wheels in the direction of the sloping surface is

$$G_\alpha = G_1 \times sin\,\alpha \tag{6}$$

To enable the robot to remain stationary on a sloping surface, the driving wheels need to provide traction force as follows:

$$F_1 = F_{f1} + G_\alpha \tag{7}$$

Due to the variable rolling friction coefficient of the bottom surface of farmland, wet sandy ground and wet soil are used as calculation cases, with rolling friction coefficients of 0.16 and 0.35, respectively.

The required torque for the driving wheel is

$$T_1 = F_1 R \approx 65.535\ N/m \tag{8}$$

Among them, R is the radius of the driving wheel.

For its torque, the robot is designed with a DC brushless wheel hub motor as the driving wheel. At the same time, since the wheel hub motor can directly act on the driving wheel, it eliminates the transmission mechanisms such as chains and gearboxes required in traditional driving systems, thus greatly saving space. The compact design allows for more efficient utilization of the robot's space design.

Due to the proximity of the wheel hub motor to the driving wheels, it helps improve the center of gravity and weight distribution of the robot. A more balanced weight distribution can improve the stability and maneuverability of robots, especially when turning or handling uneven surfaces. The chassis design of the robot drive wheel is shown in Figure 6 and Figure 7.

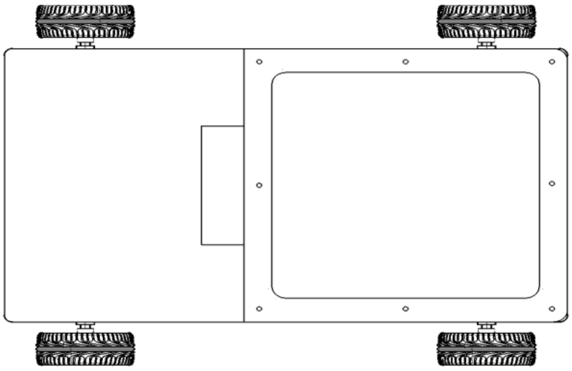

Figure 6: Design of Robot Bottom Plate Traveling Mechanism

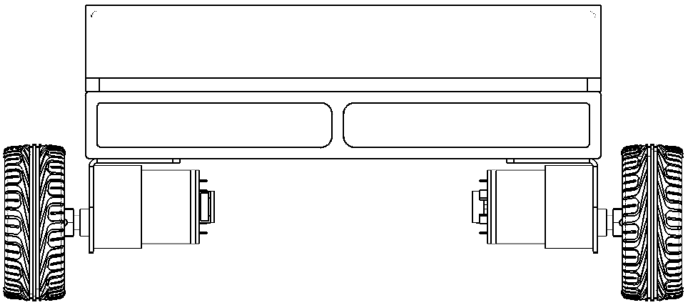

Figure 7: Design of Connection between Drive Wheel and Motor

The mobile robot adopts a symmetrical structure layout, which is symmetrical in all directions. This layout helps to maintain the balance and stability of the robot, improve its motion efficiency and control accuracy. In terms of motor selection, wheel hub motors are used, which are integrated inside the wheels to achieve a compact design, save space, reduce the complexity and energy loss of the transmission system, and improve transmission efficiency. In order to ensure the gripping ability of the mobile robot and improve the comfort and stability of driving, rubber tires are selected, and their size is coordinated with the body size.

3. Functional design

To ensure that multifunctional agricultural management robots can efficiently complete agricultural tasks, it is necessary to ensure their accurate environmental perception and the ability to control data transmission direction. The research on sensor technology is an important component of this field.

3.1 Functional Design Section

Soil monitoring: Through sensors such as soil moisture, temperature, pH value, and nutrient content, robots can obtain real-time soil conditions. These data provide important basis for precision irrigation, fertilization, etc., avoiding resource waste.

Crop growth monitoring: By using visual sensors, infrared sensors, etc., real-time monitoring of crop growth status, leaf health, pests and diseases can be achieved. These data are analyzed through image processing and machine learning algorithms to help robots make precise agricultural management decisions.

Environmental monitoring: Robots can also monitor environmental data such as temperature, humidity, and wind speed through sensors. Through data transmission and big data processing, robots can make reasonable scheduling for subsequent agricultural management decisions, providing more comprehensive support for agricultural production.

Autonomous navigation and path planning: In order to achieve autonomous work in the field, robots need to have efficient navigation capabilities. Based on GPS and visual recognition technology, robots can accurately locate their position in the fields, plan their paths, avoid obstacles, and complete predetermined tasks.

Multi robot collaboration: By designing intelligent algorithms, multiple robots can divide labor and cooperate, share data in real time, collaborate to complete large-scale agricultural tasks, improve work efficiency, and reduce costs.

3.2 Visual Recognition

The visual module located at the top of the car adopts Yolov5 module, which has the characteristics of small size and low working voltage. Its camera's UXGA image can reach up to 15 frames per second, and can fully control the image quality, data format, and transmission method. All image processing processes, including gamma curve, white balance, contrast, chromaticity, etc., can be programmed through SCCB interface. It applies unique sensor technology[8] to reduce or eliminate optical or electronic defects such as fixed pattern noise, trailing, floating, etc., improve image quality, and obtain clear and stable color images. After the visual module recognizes the plant image[9], it can transmit the information to the database, and then transmit the information to the cloud. The robot can then spray the corresponding amount of insecticide and fertilizer on the corresponding plants. The sequence of visual recognition process is shown in Figure 8.

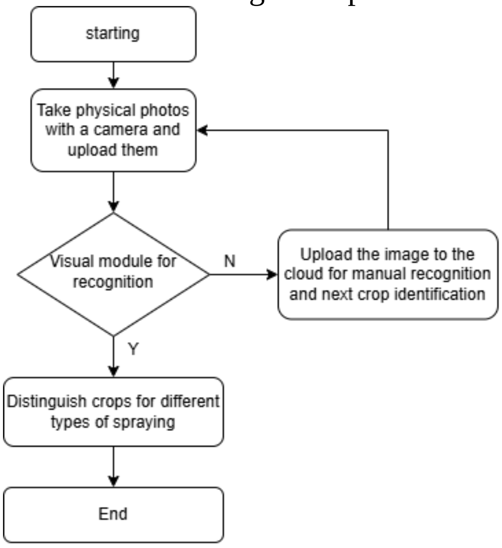

Figure 8: Visual recognition process

As shown in Figure 8, visual recognition is based on pre training the system (inputting a large number of various types of crop images to the system) to enable it to recognize and recognize. When the visual system captures crop images, it will filter, analyze, and recognize them based on the previously input crop database[10]. The corresponding crop names and similarities will be displayed on its screen[11], and the recognized information will be sent to other modules through a serial protocol for coordinated output and upload to the terminal. For example, we train the system to recognize a large number of crops in advance, classify them, and when we recognize a certain crop again, we will obtain the plant name and similarity (as shown in Figure 9, class 3 in the figure is the corresponding crop name, followed by the similarity data) and transmit the data to the remaining modules. The example in the visual recognition experiment is shown in Figure 9.

Figure 9: Example of Visual Recognition Process

4. Conclusion

This article designs a multifunctional agricultural management robot based on machine vision, which integrates pest control, pesticide spraying, and fertilization, and has the characteristics of intelligence and automation, which can help farmers work efficiently. By simulating and analyzing the hardware design of robots and designing targeted functions, it is possible to ensure that robots can efficiently, intelligently, and accurately perform their job tasks. At the same time, our group of robots actively responds to the requirements of national sustainable development, conforms to the trend of national mechanized agriculture development, and has a wide range of application space.

Acknowledgement

This work has received support from the Autonomous Region level College Students Innovation and Entrepreneurship Training Program (S20231095376X).

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