Design of a Prairie Garbage Collection Robot Based on Unmanned Aerial Vehicles

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Abstract. In response to the increasing concern over environmental protection, particularly with regards to garbage pollution and degradation in prairie scenic areas, a solution is proposed involving a multi-rotor unmanned aerial vehicle (UAV) platform equipped with a mechanical arm for efficient prairie garbage collection. The potential applications of UAV technology incorporating a mechanical arm are discussed. The design of the mechanical apparatus is elaborated, encompassing components such as the UAV's mechanical arm, body frame, and telescopic pole. Consideration factors for the UAV frame are addressed to ensure design balance and stability. By integrating image transmission devices, visual recognition, and control systems, an automated process is achieved for identifying garbage locations, flying to the garbage position, grasping the waste, and successfully depositing it into the collection unit. Research findings demonstrate that the UAV equipped with a mechanical arm offers a proficient solution for garbage retrieval in prairie terrain, mitigating risks and costs associated with cleaning efforts.

Keywords: Unmanned aerial vehicles (UAVs), Mechanical arm, PID control.

1. Introduction

In recent years, issues pertaining to environmental conservation have garnered increasing attention, with the effective resolution of garbage collection assuming significant importance in the realm of environmental safeguarding. Grasslands represent a vital component of ecosystems, playing essential roles in soil and water preservation, wind erosion prevention, and biodiversity conservation [1]. The preservation of grassland environments has become a focal point for numerous nations in recent times, wherein the litter prevalent in prairie scenic areas stands as a notable cause of grassland contamination and degradation. Presently, the predominant approach employed both domestically and internationally for prairie garbage collection relies on manual efforts by sanitation personnel. However, due to the expansive and open nature of grassland terrains, this method not only incurs substantial costs but also exhibits inefficiencies and potential oversights. The substitution of inefficient human labor with intelligent mechanisms has evolved into a global trend. As technologies such as mechanical fabrication and intelligent control have rapidly advanced, the low cost, minimal operational and maintenance expenses, maneuverability, and adaptable equipment carriage capabilities of small unmanned aerial vehicles (UAVs) have led to their extensive attention and application across various domains, encompassing tasks such as mapping, forest fire detection, aerial photography, and equipment maintenance [2], particularly in inaccessible or remote regions [3].

While the proliferation and broad spectrum of UAV applications have primarily centered on observation and monitoring, with minimal direct interaction with the physical environment, this does not encapsulate the entirety of their potential utility. Researchers have commenced investigations into UAVs equipped with mechanical arms for object manipulation and have executed practical applications of such UAVs [4-8].

Facing the challenge of garbage collection, the integration of mechanical arm-equipped UAV technology presents a promising avenue for effective solutions. Concurrently with the advancement of multi-rotor UAV technology on both domestic and international fronts, researchers have proposed designs for garbage collection UAVs tailored to intricate terrains like snowy mountains and

marshlands [9, 10]. The agile maneuverability of multi-rotor UAVs facilitates swift traversal across complex and expansive terrains such as snowy mountains, marshes, and deserts, thereby enabling efficient waste retrieval through UAV-mounted mechanical arms. In order to ensure the safety, reliability, risk mitigation, and avoidance of potential human and property losses, along with substantial enhancements in work efficiency and cost reduction, the adoption of UAVs with mechanical arm attachments for garbage retrieval becomes imperative [11].

In the context of prairie landscape, UAVs equipped with mechanical arms offer notable advantages such as wide operational range, accessibility to locations inaccessible to ground-based robots, high object retrieval efficiency, and reduced labor costs [12]. Currently, neither mature solutions for garbage collection in prairie terrains nor extensive research on multi-rotor UAVs equipped with mechanical arms exist, as these technologies are still in their nascent stages of development, with corresponding applications yet to reach full maturation.

The rotary-wing UAVs has been utilized as the platform and incorporating mechanical arms as the design solution, endeavors to supplant manual cleaning efforts, thereby achieving efficient garbage collection within prairie landscapes. By selecting suitable power systems, designing mechanical arm systems, flight control systems, and electronic control systems, and rationally planning the positioning of various structural components, this approach seeks to realize effective garbage cleanup within prairie scenic areas.

2. Method

2.1. Overall Design Concept

The prairie garbage collection robot proposed in this paper mainly consists of a flight power system (electric helicopter wings and support brackets), a control system (camera and sensing devices), and mechanical components (single-axis robot, ball screw mechanism, and mechanical claw).

Based on the functionalities required for garbage collection in the prairie environment using unmanned aerial vehicles (UAVs), the robot is divided into two main parts: the flight system and the mechanical system. This paper primarily focuses on the mechanical system, specifically the UAV's mechanical arm and body frame, as the design of this mechanical system plays a decisive role in the UAV's ability to grasp and release garbage.

As the bottom of the UAV is connected to the mechanical arm, the weight of the UAV becomes a critical consideration. The weight of the mechanical arm should be minimized while ensuring its structural integrity to avoid excessive power consumption or operational issues caused by an overweight UAV.

Furthermore, to maintain the UAV's balance during flight, the initial positioning of the mechanical arm needs special attention to ensure smooth flight after installation. Based on the structural characteristics and center of gravity analysis, the mechanical arm should be mounted at the center position of the UAV.

Additionally, considering the smooth landing of the UAV and the specific characteristics of the prairie environment, the external frame of the UAV is also of great importance. Such a design approach allows the UAV to perform garbage collection without hovering in the air, enabling it to grab the garbage after landing and thus reducing power consumption and improving operational efficiency.

To ensure that the mechanical claw does not contact the ground and get damaged during landing and to facilitate convenient garbage collection, a vertical direction for the mechanical arm is designed to be adjustable and extendable. The design scheme of the prairie garbage collection robot is shown in Figure 1.

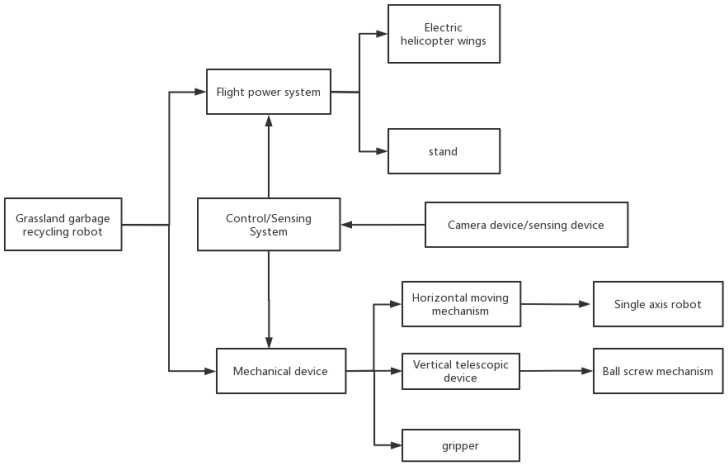


Figure 1. Designing scheme

2.2. Mechanism Operation Process

The overall control process of the garbage collection UAV is complicated, with the main operational steps outlined below:

(1) The camera on the UAV serves as an image transmission device, synchronously transmitting the aerial video from the UAV's perspective to the client-side.

(2) Based on the received images, the system automatically identifies the location of the garbage and approaches the designated area.

(3) Once the garbage location is successfully identified, the UAV flies directly above the garbage, adjusts its attitude, and prepares for landing.

(4) Leveraging visual recognition, the control system commands the motors to adjust the mechanical arm's position to be directly above the garbage. The mechanical claw is then opened, and the arm is vertically extended until it makes contact with the garbage. The mechanical claw then grasps the garbage securely.

(5) The UAV returns to the collection point or designated area and deposits the collected garbage into the specified collection unit.

(6) The UAV repeats the above actions to search for the next target for collection until all garbage collection is completed or the mission is terminate.

3. Structure Overview

3.1. Drone Rack Section

Unmanned aerial vehicle (UAV) airframe, also known as the UAV frame or chassis, serves as the primary supporting structure of the UAV. It is constructed using lightweight, high-strength materials and functions to bear critical components and transmission systems. The design of the airframe typically takes into account flight performance, structural integrity, weight optimization, and vibration resistance. The 3D design of the prairie garbage collection robot is shown in Figure 2.



Figure 2. 3D design of the prairie garbage collection robot

3.2. Single-axis Robot

The single-axis robot is a linear motion system commonly utilized to achieve smooth linear movements, serving as a platform for providing linear motion to the mechanical arm. The design of the sliding rail must take into consideration factors such as friction, precision, and stability to ensure that the telescopic pole can smoothly slide during its motion. Figure 3 shows the single-axis robot design drawing.

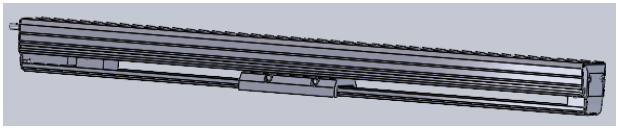


Figure 3. Single-axis robot design drawing

3.3. Telescopic Pole

The telescopic pole is a mechanical component with the ability to extend and retract, commonly used to achieve variable-length linear motion. By employing a motor-driven ball screw mechanism, the pole's telescoping function is enabled, allowing it to adapt to the gripping requirements of objects at different heights. The design of the telescopic pole necessitates consideration of precision, stability, and load-bearing capacity to ensure accurate positioning of the mechanical arm during object grasping operations. Figure 4 shows the telescopic pole design drawing.



Figure 4. Telescopic pole design drawing

3.4. Dual Degree-of-Freedom Mechanical Claw

The mechanical claw achieves gripping and releasing actions through a motor-driven link mechanism and accomplishes axial rotation via motor-driven gear transmission, enabling dual degrees of freedom. The design of the mechanical arm must take into account its degrees of freedom, precision, and load-bearing capacity to ensure accurate execution of gripping actions and the ability to carry and manipulate target objects.

Overall, this project integrates knowledge from multiple disciplines, including UAV technology, sliding rail systems, telescopic pole design, and mechanical arm control. These components work together to provide the UAV with a certain level of autonomy and operational capability, aiming to create an intelligent robotic system capable of object grasping through a UAV platform. The mechanical claw design drawing is shown in Figure 5.

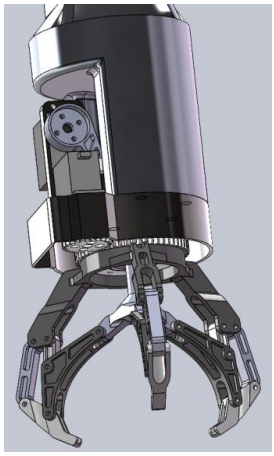


Figure 5. Mechanical claw design drawing

3.5. Camera

The Wescam MX-15 camera is selected for this application, featuring an electro-optical infrared sensor system that enables garbage recognition from high altitudes, significantly enhancing garbage search efficiency. Figure 6 shows the diagram of the camera.

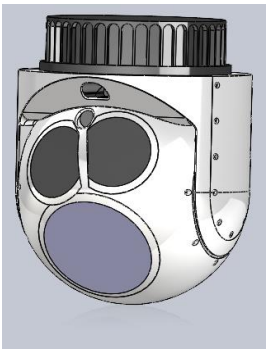


Figure 6. The diagram of the camera

3.6. UAV Wing

The overall size of the drone is relatively large, and selecting a model helicopter as the power unit can effectively control the movement of the drone and provide lift. Figure 7 shows the UAV wing design drawing.

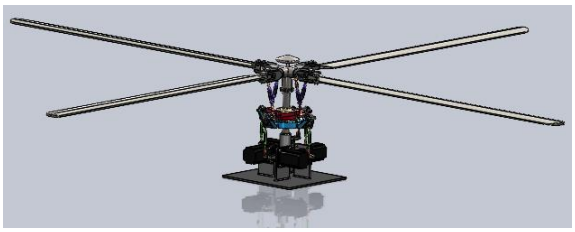


Figure 7. The UAV wing design drawing

3.7. Simulation Results of Mechanical Arm

For the simulation of the robot, a motor with appropriate parameters is introduced to drive the movement of the mechanical claw. The simulation parameter curves of the central axis of the mechanical claw are shown in Figures 8, 9 and 10.

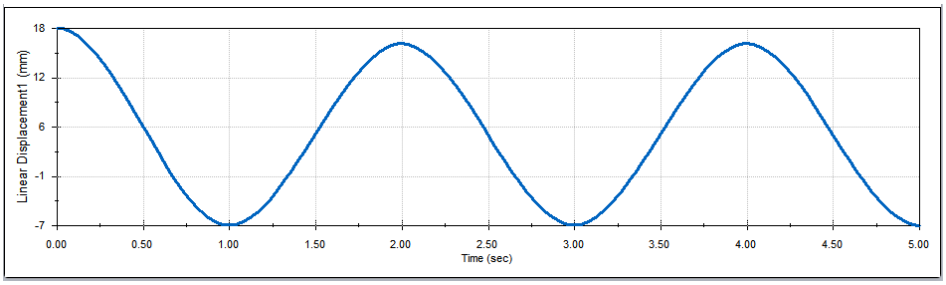


Figure 8. Mechanical claw center axis displacement curve

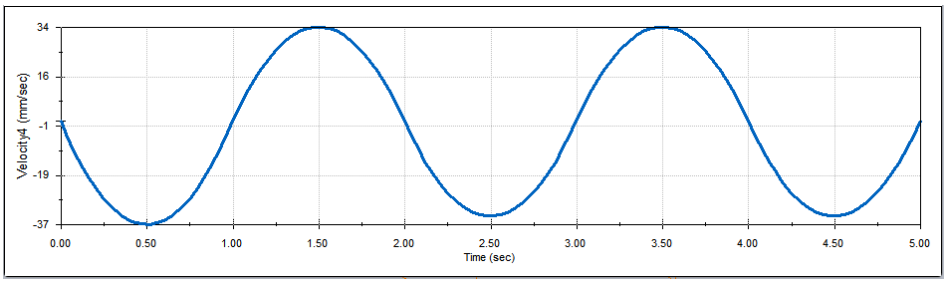


Figure 9. Mechanical claw center shaft speed curve

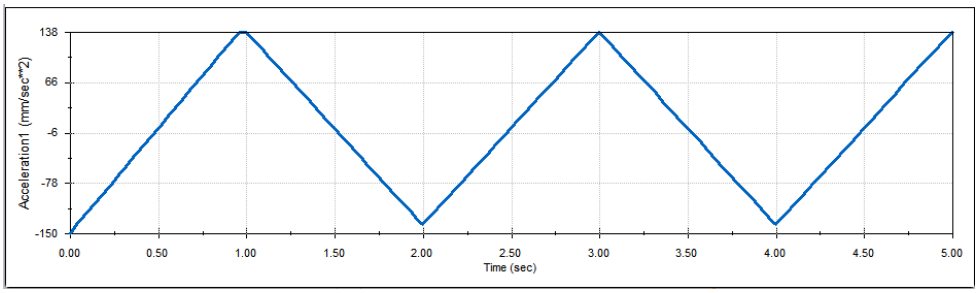


Figure 10. Mechanical claw center axis acceleration curve

4. Discussion

4.1. PID Control of the Mechanical Arm

The fuzzy PID algorithm combines fuzzy control theory with PID algorithm, where fuzzy theory is implemented using the basic concepts of fuzzy sets or continuous membership functions. By integrating these two algorithms, it can avoid the shortcomings of using them separately and achieve optimal control objectives [13]. Applying the fuzzy PID algorithm to the mechanical arm in this study aims to enhance the stability and control effectiveness during gripping and movement.

The control performance of the fuzzy PID control algorithm depends on its control rules, and the number of control rules exponentially relates to the number of controller inputs. During the system operation, the input quantities are the error and the rate of change of the error. The control principle of the fuzzy PID algorithm is illustrated in the following figure.

The coefficients of proportionality K_p, integration K_i, and differentiation K_d, which are adjusted, compose the control signal. The proportionality coefficient K_p reflects the relationship between the controller's output and input error, and increasing this coefficient can reduce the steady-state error of the system, thereby improving the stability of the system [13]. The integration coefficient is mainly used to eliminate steady-state error, gradually reducing the steady-state error over time until it reaches zero. The differentiation coefficient enhances the operational stability of the controller. In this study, the purpose of the mechanical arm is to achieve fast, precise, and stable garbage gripping. Through fuzzy PID control, the errors in the lateral and vertical movements of the mechanical arm are reduced, leading to more accurate gripping positions and better accomplishment of the mechanical arm's tasks. Figure 11 shows the fuzzy control flow.

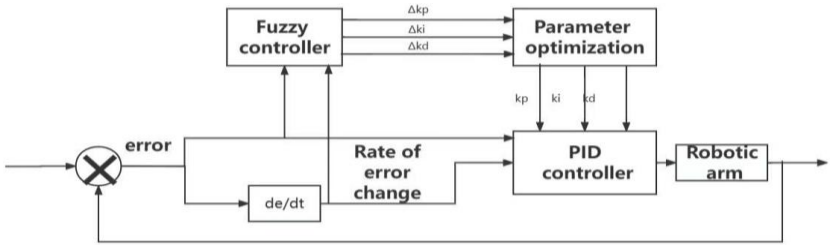


Figure 11. Fuzzy control flow chart

5. Control Process

The system employs a high-performance, reliable, and versatile DSP (Digital Signal Processor) chip for digital image transmission. The DSP chip enables simultaneous parallel processing of multiple operations, significantly enhancing the robot's performance in image processing and data transmission. Upon initiation of the UAV control program, the image acquisition device, Wescam MX-15 camera, starts functioning. The image data is converted into streaming data using TCP protocol and then encoded before being transmitted to the client-side. The client utilizes a D/A converter to receive the image data, achieving synchronization between the UAV's camera and the client's image information. Additionally, the client is equipped with the appropriate SSD (Single Shot

Multibox Detector) algorithm, which differs from the YOLO algorithm by directly utilizing convolution to detect various feature maps. This approach greatly improves the detection efficiency for objects of different sizes. When applied to this project, where the size of the prairie garbage cannot be predetermined, the SSD algorithm demonstrates high-speed operation and superior detection accuracy, providing a more efficient approach for garbage recognition.

Upon successful detection, the UAV initiates the landing procedure and activates the gripping program, which controls the stepper motors and servos to position the mechanical arm accurately, extend, and grasp the target garbage. Subsequently, the UAV returns to the collection point and disposes of the garbage, repeating the process until the garbage collection is completed. The control flow chart is shown in Figure 12.

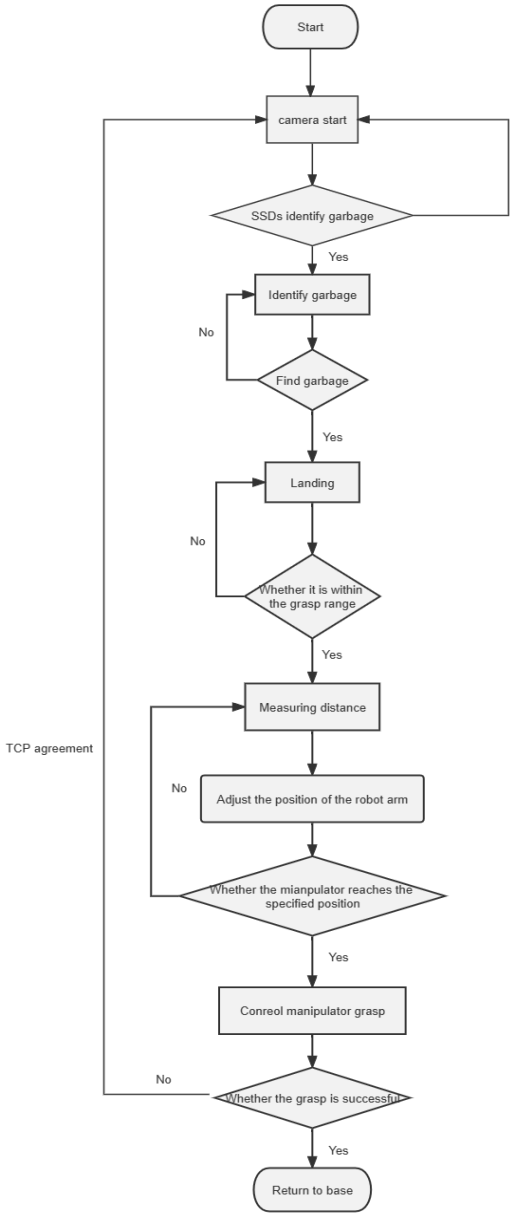


Figure 12. Control flow chart

6. Conclusion

To achieve intelligent garbage collection in prairie environments, this paper presents a design of an intelligent robot equipped with a mechanical arm, mounted on a UAV for operation in prairie scenic terrains. The design incorporates Solidworks 3D modeling, image transmission devices, and fuzzy PID control as the primary research methods, while leveraging a camera for garbage recognition

and identification. This approach provides an efficient and autonomous solution for cleaning up garbage in the prairie environment. The research has significant positive implications for environmental protection and ecological balance. With continuous technological advancements and improvements, it is expected that this intelligent robot will play an increasingly crucial role in the field of prairie garbage collection, contributing to the creation of a green and beautiful prairie environment.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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