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UAV Grazing Research

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Abstract: UAVs have the characteristics of flexibility and ease of operation and have become an important tool for breaking terrain barriers, safely and efficiently obtaining massive amounts of surface data, and low-altitude and near-Earth observations in research such as geographic information science and ecology. In addition, UAVs have been applied in grassland animal husbandry management and assisted grazing. The research first systematically reviewed the progress of UAV grazing-related technologies and the typical application cases of UAV-assisted grazing in China and abroad. Then, combined with the UAV grazing livestock experiment carried out by the research team in Hulunbuir, China, the grazing effect of the UAV on different herds in different driving positions of the herd was analyzed. The preliminary results of the experiment show that UAVs have great application potential in assisting grazing and that the grazing effect of UAVs equipped with megaphones is better than that of UAVs without megaphones. Finally, the existing problems and challenges of UAV grazing are discussed, and the future development directions are proposed. The analysis of UAV flight height, attitude, noise, and other factors influencing the herd driving effect is conducive to the formulation of standardized UAV herding livestock standards and can also provide a theoretical reference for responding to the demand for highly intelligent UAV grazing in the grassland environment.

Keywords: UAV grazing; typical application cases; the effect of supplementary grazing; loudspeaker

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1 Introduction

The rapid progress of information technology promotes the continuous development of geographic science. The explosion of UAV applications directly promotes the integration of low-altitude and near-Earth remote sensing technology with other disciplines, forming a new application model of "UAV+" [1]. The full name for UAV is "Unmanned Aerial Vehicle", which refers to an unmanned aircraft controlled by radio remote control equipment and

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self-provided program control devices. According to the platform configuration, there are mainly fixed-wing UAVs, multi-rotor UAVs, and unmanned helicopters. UAVs were first used in the military field, and then demand in the civilian field increased and developed rapidly. At present, UAVs are widely used in land surveying, plant protection operations, disaster relief, wildlife observation, and other fields[2]. The introduction of UAVs has provided new and efficient technical means and innovative solutions for many industries and has also greatly expanded the breadth and depth of UAV applications[3]. The grassland pastoral area is special in geographical research; its distinct geographical advantages and natural conditions endow it with unique animal husbandry resources[4]. Traditional grassland grazing is mainly based on human labor. With the development of society, the advent of the era of UAVs has put forward new requirements for the development of grassland animal husbandry. Exploring the deep integration of UAVs and animal husbandry is conducive to optimizing the grazing methods of grassland animal husbandry, improving animal husbandry production efficiency, promoting the informed development of animal husbandry, and realizing the real-time dynamic monitoring of herds, which has important research significance and practical application value.

Before the 1990s, the grazing methods of grassland herdsmen in China were mostly on foot or horseback; since the 1990s, motorcycles have gradually replaced horses as the preferred auxiliary grazing tool for herdsmen[5]. Before the 1970s, foreign herdsmen mostly used horses or cars as their main grazing tools; after the 1970s, some large foreign pastures began to use small helicopters to assist grazing efforts[6]. Compared with on-foot methods, horseback riding or motorcycles greatly improved the grazing efficiency, but it was still necessary for herdsmen to follow the herd at all times. In addition, in areas such as alpine grasslands, highlands, mountains, and forests, the geographical environment is complex, and it was difficult for horses and motorcycles to follow. However, with helicopters, it was possible to quickly follow and monitor a large area in pastoral areas regardless of the terrain, but the cost was too high; the driver needed professional flying skills, which is not universal. In recent years, UAV-related technologies have gradually matured, and the manufacturing cost has dropped rapidly. As a result, UAVs have been widely used in various fields. Some herdsmen in China and abroad have incorporated the use of UAVs to assist in grazing[7]. UAVs are small in size, easy to carry, and highly maneuverable. They can quickly obtain image data of ground targets from long distances and transmit them to the receiving terminal on the ground in real time through sensors, which is helpful for collecting herd information and herd management. This paper systematically sorts out UAV applications in grazing and discusses the problems and challenges of UAVs in the field of assisted grazing, as well as the future development direction, combined with the Hulunbuir UAV grazing livestock experiment.

2 The Application of UAV in Animal Husbandry

2.1 Animal Identification and Counting

Animal identification and counting are among the most important applications of UAVs in animal husbandry. For a long time, it has been difficult to quickly and accurately count the number of large-scale livestock. The application of UAVs can greatly improve the accuracy and speed of quantitative statistics[8]. UAVs equipped with high-definition resolution cameras can obtain orthophotos of herds from low altitudes near the ground and achieve accurate animal population counts through artificial visual interpretation or computer vision target detection. Human visual interpretation based on UAV images has been widely used in animal population surveys. Xu *et al.* used UAVs to investigate the ecological diversity of wetland birds in the Momoge International Nature Reserve. The direct counting method was used to count the population of geese and ducks in the image, which provided accurate data support for the research on the diversity status of geese and ducks and waterbirds in the

Momoge wetland and habitat selection[9]. Wang *et al*. replaced conventional wildlife survey methods with UAV technology and obtained accurate and complete information on the distribution, number, and movement trajectories of Asian elephants through visual identification and manual counting of aerially photographed animal images[10]. Vermeulen *et al*. used a UAV equipped with a high-resolution visible light and thermal imaging camera to investigate the population of African elephants in the southern hunting grounds of Burkina Faso, Africa, based on traditional wildlife survey methods, with high accuracy[11].

The animal population counting method based on manual visual interpretation has a low degree of automation. The accuracy mainly depends on the operator's professional quality and subjective judgment, which is not objective and factual. In addition, visual interpretation is difficult to process in the face of large population counts. High-resolution aerial images have become increasingly common worldwide in recent years, providing a data basis for converting existing automatic or semi-automatic animal population counting to high-precision and high-automatic target recognition and counting. In addition, the maturity of deep learning technology has recently been applied to animal recognition[12]. Hodgson *et al*. used a deep learning network model to research seabird identification and counting based on UAV images and compared the experimental reports of seabird populations using traditional ground survey methods and UAV survey methods, respectively. The results show that the statistics of the human-machine automatic counting survey method are more accurate[13]. Linchant *et a*l. used UAV and iMUAS software to count the number of hippopotami in two hippopotamus parks in Galaba National Park, Democratic Republic of Congo, and the statistical results were very close to the true value provided by local staff[14]. Wu *et al*. used Inspire2 and the MavicPro UAV to automatically detect the number of large herbivores in Sanjiangyuan. After the accuracy testing method allowed for the comparison of manual and automatic counting results, the relative average error was 4.8, which can be realized in most cases[15]. Although the UAV-based deep learning counting and statistical method still contain certain errors, it can provide a great advantage in estimating large-scale populations, providing data for ecologists to study grassland stocking statistics and wild animal population estimates.

2.2 Livestock Positioning

The BDS (BeiDou Navigation Satellite System), independently developed by China, is an important national space infrastructure tool that can provide users with high-precision positioning, navigation, and timing services. As of July 2020, BDS-3 has been built and has begun to provide global services. After inspecting the special terrain of Changdou village, Mao county, Aba prefecture, Sichuan province, Li *et al*. proposed the use of satellite positioning technology and UAV technology to achieve "Beidou grazing" to build an "aviation ecological pasture"[16]. In this application, the livestock wear a special collar with a positioning function on the neck for each herd. The Beidou positioning module and infrared temperature measurement module are equipped in the collar to transmit position and livestock body temperature information. The UAV flies over the pasture to collect collar information and transmits the coordinate information to the herdsman's mobile phone application to form an information loop. In this way, the herdsman can obtain real-time information on the herd's location from a long distance. Once the herd or individual deviates from the range of the pasture, the herdsman can drive the UAV to drive it on the spot. The positioning accuracy of the Beidou system can reach 1.2 m, and the speed measurement accuracy can reach an accuracy of 0.2 m/s, which fully meets the requirements of herdsmen to control the herd. An "Aviation Ecological Ranch" simplifies the herdsman's grazing process. Herdsmen do not need to go over the mountains to find the herd. For individual livestock that cross the border, the location information of the individual can be transmitted to the UAV. After the UAV finds the individual, it can be manually controlled to drive away, which improves the grazing efficiency. Wu, Wanquan, a villager in Songdou village, used the Beidou grazing system to perform unmanned management of 20 cattle, and the grazing and driving effect was excellent[16].

2.3 Livestock Drive

In European countries such as the United Kingdom and the Netherlands, herders use UAVs for herd management, e.g., to drive grazing. New Zealand, known as the "nation of sheep", is setting off a new wave of UAV herding. The traditional way of grazing in New Zealand is large-scale grazing in the wild. The sheep move freely in the Southern Alps most of the year. In autumn, the herds that roam around the extensive pasture will be driven back to the gentle and warm low-altitude grasslands. However, driving the herd is often difficult. The herd moves freely for a long time, and their location is scattered; the grassland is vast, the pasture is wide, the terrain is complex, there are many mountains and ravines, and the efficiency of a manual search is low. In addition, herdsmen in New Zealand tend to be large in size, and it is very difficult for herdsmen to drive a nearly 1,000-kilometer-long flock under complex terrain. The local traditional driving method is to take the shepherd dog to the top of the mountain by helicopter and search down from the top to drive it away, which is time-consuming and labor-intensive. The investment in a UAV weakens the intensity of this work. With the help of the high-altitude perspective of a UAV, herdsmen can quickly locate the flock, and use the UAV to guide the direction of movement of the sheep in different flight attitudes, thereby replacing the herdsmen to drive them out in person, greatly reducing the herd search time.

New Zealand herdsman Tony Buchanan owns 5,210 sheep. He has a large herd and it is time-consuming and laborious to drive manually. He often uses the DJI Phantom 4 RKT UAV to assist in grazing. Tony Buchanan controlled the flying height of the UAV at 5–10 m when driving, and used the noise from the propeller to interfere with the movement of the sheep. In addition, the shepherd dog was used to drive it away, forming a new grazing method that combines UAV and shepherd dogs[17]. The battery life of a single flight of the UAV is about 30 minutes. After returning to the flight with a low battery, you can return to the home point and work again. With the help of the aerial images collected by the onboard camera, locating the flock and looking down on the flock is very convenient. The ability to locate the herd shortens the grazing time from 5 hours to around 2 hours.

Brett Sanders, a farmer, has more than 8,000 sheep on his ranch. He uses the MATRICE M200 UAV to monitor and search the flock. Most of Brett Sanders' pastures are in the mountains. In the past, it took three hours to drive the sheep with herding dogs, but with the assistance of the MATRICE M200, the time to drive the sheep was shortened by 50%[17]. An Israeli farmer developed a UAV-based autonomous grazing system with the help of a visual deep learning algorithm and used the Mavic 2 UAV equipped with this system to autonomously identify the cattle on the grassland using the physiological response characteristics of the cattle to the UAV to drive away the herd. This system greatly reduces the operating cost of the ranch and improves the efficiency of herdsmen's wild grazing[18]. Another New Zealand herdsman, Jason Rentoul, uses the consumer UAV DJI Phantom4 Advance to manage cattle[19]. Jason Rentoul made a simple transformation based on the original machine: Jason Rentoul added an audio player to the UAV, and the UAV played the bark and the Star Wars movie episode alternately to the flock through the UAV. After hearing the stimulation of the noise, the herd's instinctive fear prompts them to quickly concentrate and run away from the sound source. The comparative analysis of practical results shows that UAV herding is far more efficient than herding dogs, and the driving effect of UAV is significantly better than that of herding dogs when driving cattle, especially cattle with calves. Cattle are more likely to be aggressive and out of control when faced with dogs, while UAVs do not cause aggression in cattle. The specific parameters of the UAV involved above are shown in Table 1.

Table 1 UAV partial parameter list

Livestock species	UAV	Control distance/m	Image sensor	Battery capacity /mAh	Hover accuracy /m	Wheelb-ase /mm	Flight time /min	Source literature
Sheep	DJI Phantom 4 RKT	FCC:7000; CE:3500 SRR:4000	1-inch CMOS, 20 million effective pixels	4,920	V: ±0.1 H: ±0.1	350	30	15, 19
Sheep	DJI Phantom4 Advance	FCC:7000; CE:3500 SRR:4000	1-inch CMOS, 20 million effective pixels	5,870	V: ±0.1 H: ±0.3	350	30	15
Sheep	MATRICE M200	FCC:7000; CE:3500 SRR:4000	1-inch CMOS, 20 million effective pixels	4,280	V: ±0.5 H: ±1.5	643	27	16
Sheep	Mavic 2	FCC: 7000; CE: 4000 SRR: 4000	1-inch CMOS, 20 million effective pixels	3,850	V: 0.1m H: 0.3m	354	31	17

3. Hulunbuir UAV Grazing Livestock Experiment and Discussion

The UAV grazing experiment was conducted in the Chenbarhu Banner Ranch in Hulunbuir City. Hulun Buir Grassland is located in the northeast of Inner Mongolia autonomous region, on the Hulun Buir Plateau west of the Greater Khingan Mountains. It is a world-famous plateau pasture. The aircraft used was the DJI Phantom 4, and the experimental objects were sheep, cattle, and donkeys. This research experiment tested the grazing of DJI Phantom 4 on different livestock at different flight heights using different approaches (from the edge of a group or individual, approaching back and forth) and driving means (the UAV itself and its noise, shouting through a megaphone). From August 15, 2020 to August 31, 2020, a total of 24 UAV grazing experiments were carried out under the conditions of good weather and in a grassland environment. These were recorded from the perspective of an aerial UAV and ground mobile phones. The Hulunbuir UAV grazing livestock experimental dataset was obtained upon completion of the experimental process. The effects of UAV grazing are discussed separately by herd type.

3.1 Aircraft and Megaphones

The UAV product used in the experiment is the DJI Phantom 4, with a mass of 1,380 g, a battery capacity of 5,870 mAh, a maximum ascent speed of about 6 m/s, and a hovering accuracy of 0.1 m in the vertical direction and 0.3 m in the horizontal direction. The maximum communication distance is about 5,000 m, and the flight time is 30 minutes. In addition, the UAV has three innovative functions of obstacle perception, intelligent following and pointing flight, which can provide important help in the grazing process. The UAV microphone used in the experiment is adapted to the DJI Phantom 4, and the installation method is bundled installation. The megaphone adopts digitally encrypted transmission without interference. The mass of the airborne end is about 115 g, with low noise and high voice recognition. The weight of the megaphone is within the onboard carrying capacity of the UAV and does not interfere with the normal operation of the UAV.

The main parameters of the aircraft are shown in Table 2, and the main parameters of the high-altitude megaphone are shown in Table 3.

Table 2 List of some parameters of UAV used in the experiment

Product name	Control distance /m	Image sensor	Battery capacity /mAh	Hover accuracy /m	Product mass /g	Wheelbase /mm	Flight time /min	Maximum wind speedm/s	Working temperature (°C)
DJI Phantom 4	FCC: 5,000 CE: 3,500	1-inch CMOS, 2 million effective pixels	5,870	Vertical:±0.1 Horizontal:±0.3	1,380	350	30	10	0–40

Table 3 The parameter list of the pager used in the experiment

Product name	Sound transmission distance /km	Transmit power /w	Radio frequency /MHz	Volume /cm^3	Mass /g	SPL /dB	Charging time/h	Battery life/h	Waterproof level
UAV megaphone	5–10	5	433	7×5.5×5.5	118	125–140	2	4	IPx 4

3.2 UAV Herding Sheep

UAVs are used to drive the flock from the center of the flock, the tail of the flock, and both sides of the flock along the direction of movement of the flock or perpendicular to the direction of movement of the flock. An unloaded UAV and a UAV equipped with high-altitude megaphones were used to carry out 2–3 sheep herding experiments in different driving positions, for a total of 17 times. The experiments were divided into eight groups and judged the effect of UAV herding from three aspects: the reaction time of the herd, the movement state of the herd, and the accuracy of the movement direction of the herd. The herd reaction time refers to the time from when the UAV starts to drive the herd to the time when the herd responds; the movement state of the herd is the movement speed of the herd and the dispersion of the herd during the driving process of the UAV; the movement direction of the herd is assessed according to whether the herd is moving in the direction of the target drive. In the shepherd experiment, the UAV chased the sheep at a height of 20 m and adjusted to the experimental flight height after reaching the driving position. During the driving process, the flying speed and direction of the UAV are adjusted in real time according to the movement state of the flock. The driving process and effects of the UAV herding experiment are shown in Table 4 and Figure 1. Each experiment lasts about fifteen to twenty minutes.

According to the analysis of the experimental results, the effect of the UAV on the sides and tail of the flock is better than that in the center of the flock. The shepherd effect of the UAV equipped with a megaphone is better than that of the UAV without a megaphone. Within the transmission range of the UAV noise and the sound of the megaphone, the difference of the UAV flying height on the flock driving effect is not obvious.

Sheep are docile, timid, and sensitive to sudden changes in the external environment. When the UAV flies to the center of the flock at a height of about 16 m above the flock, they will slowly scatter around with the location of the UAV as the center, and the direction of movement is not clear. After about 30 s, the flock bypassed the UAV and regrouped. When the UAV, without a megaphone, approached from the rear of the herd to drive them away, the sheep quickly gathered and moved forward slowly in the direction away from the UAV. The UAV was manipulated to follow the sheep, and when the UAV approached the sheep again from the tail, the flock accelerated and continued to move away from the UAV. When the UAV equipped with the high-altitude megaphone approaches the flock from the tail, the herdsmen shouted to the flock through the walkie-talkie to assist the UAV upon diving to drive the flock. The flock quickly gathered, moved faster, and had a shorter reaction time. In the two shepherd experiments in which the herd was driven from the tail, the sheep moved quickly and accurately in the direction of the UAV, and the movement of the sheep was stable. When the UAV, without a megaphone, swooped in and drove from both sides of the flock in the direction of the flock's movement, the flock quickly moved away from the UAV in the direction perpendicular to the movement of the UAV, and the overall speed of the flock was uneven. Specifically, the movement speed of the flock farther away from the UAV is significantly slower than that of the sheep close to the UAV, the movement state is chaotic, and its direction is unclear. When the UAV equipped with high-altitude megaphones dived in from both sides of the flock in their direction of movement and perpendicular to their direction of movement, the herdsmen continued to shout to the flock. The flock quickly gathered together after hearing the sound and moved quickly and steadily in the direction away from the UAV. After observing the eight groups of sheep herding experiments, it can

Table 4 Experiment of sheep herding by UAV

Experimental subjects	Experiment time	Coordinate	Number of livestock	Whether the UAV carries a payload (UAV megaphone)	Flying height/m	UAV driving method and process	UAV herding sheep effect
Sheep	2020.08.15 09:24	120.0315, 49.3809	425	No	16	The UAV flew to the center of the flock without a megaphone, and dived along the direction of the flock of sheep	The flock scatters in all directions and gathers again after leaving the UAV rotor noise area. The reaction time is short and the response is fast. The movement of the flock is slow, the movement state is chaotic, and the direction of the group movement target is unclear
Sheep	2020.08.15 10:12	120.3025 49.3797	425	Yes	15	The UAV is equipped with a megaphone and flew to the center of the flock. With the help of the herdsmen's shouting, it swooped and drove the flock of sheep in the direction of movement	The flock scatters in all directions. After leaving the UAV rotor and the megaphone sound transmission area, they gather together again. The reaction time is short
Sheep	2020.08.15 16:40	119.9548 49.3257	856	No	12	The UAV flew to the tail of the flock without a megaphone, and swooped in the direction of the movement of the flock of sheep	Sheep gather together in a group and move along the flight direction of the UAV. The movement speed is slow and the reaction speed is fast. The movement state is gradually stable and orderly from chaos, and the direction of the group movement target is clear
Sheep	2020.08.16 13:34	119.9007 49.3058	154	No	12	The UAV flew to the tail of the flock without a megaphone, and dived in the direction of the flock of sheep	The flock moves along the flight direction of the UAV, with fast movement speed and rapid response, the movement state is gradually stabilized from chaos, and the direction of the group movement target is clear
Sheep	2020.08.26 09:20	119.9367 49.3129	300	Yes	15	The UAV is equipped with a high-altitude megaphone and flies to the tail of the flock. With the help of herdsmen's shouting, it swoops and drives the sheep along the movement direction of flock of sheep	The flock moves along the flight direction of the UAV. The movement speed is fast, the response is very fast, the movement state is stable, and the group movement target direction is clear
Sheep	2020.08.26 10:15	119.9354 49.3139	356	No	7	The UAV is not equipped with a megaphone and flies to both sides in the direction of the flock, and swoops and drives it along the direction of the flock of sheep	The flock moves in the direction away from the UAV. The movement speed is fast and the response is relatively fast. The movement state is gradually stabilized from chaos, and the direction of the group movement target is clear
Sheep	2020.08.26 10:45	119.9372 49.3139	356	Yes	7	The UAV is equipped with a high-altitude megaphone and flies to both sides of the flock. With the help of herdsmen's shouting, it swoops and drives in a direction perpendicular to the movement of the sheep	The flock moves rapidly in the direction away from the UAV, the response is relatively fast, the movement state is stable and orderly, and the direction of the group movement target is clear
Sheep	2020.08.30 11:20	119.9339 49.3135	356	Yes	5	The UAV is equipped with a high-altitude megaphone and flies to both sides of the flock. With the help of herdsmen's shouting, it swoops and drives the sheep along the movement direction of the flock	The flock moves rapidly in the direction away from the UAV, the response is very fast, the movement state is stable and orderly, and the direction of the group movement target is clear

Figure 1 Experimental results of UAV shepherding

be seen that the sheep are sensitive to the herdsmen's voices. When listening to the shouts, the sheep will quickly gather together and move in the target direction under the interference of the UAV. In addition, there is an adaptation process for the sheep to be driven by UAV: the sheep are afraid of UAV at the beginning, and when the UAV starts to approach, the sheep will respond quickly and run, resulting in a movement state that is relatively chaotic. After the UAV hovers over the flock for a while, the flock becomes familiar with the sound of the UAV. At this time, the tail of the flock is slightly driven to move towards a specific target direction. The UAV herding experiments were carried out in three different locations. In the UAV driving experiment carried out in three different positions of the flock, except that the movement of the flock would be chaotic when the flock was driven at the center of the flock, the flock was successfully driven to the water tank near the flock in other positions.

3.3 UAV Herding Cattle

A total of six experiments were carried out using the UAV with and without high-altitude megaphones to drive the cattle in the center and tail of the herd, respectively. The cattle-herding effect of the UAV is judged from three aspects: the reaction time of the herd, the movement state of the herd, and the accuracy of the direction of the movement of the herd. During the driving process, the flight altitude, speed, and flight direction of the UAV were adjusted in real time according to the movement state of the herd. The driving process and effect of the UAV cattle herding experiment are shown in Table 5 and Figure 2.

According to the experimental analysis, the driving effect of the UAV at the tail of the herd is better than that at the center of the herd; the cattle grazing effect of the UAV equipped with the high-altitude microphone is better than that of the UAV without the high-altitude microphone.

The herd has a weak tendency to live in groups, and the stations are scattered when feeding. When using a UAV to drive the herd, it is necessary to drive out the outliers individually. When the UAV flies to the center of the herd at a flying height of 10 m, the individuals close to the UAV stop moving and watch the UAV; control the UAV to dive down and drive away, and the cattle closer to the UAV will move away from the UAV. The direction of the man-machine moves, but the movement state of the individuals far away from the UAV does not change. When the UAV without a megaphone flies to the tail of the cattle herd at a flight height of 2 m and dives in to drive them, the cattle at the tail slowly retreat in the direction of the UAV's flight, and the cattle in front are also affected by the backward movement of the cattle at the rear. When the UAV moves in the direction of flight, the herd moves slowly towards the driving direction of the UAV; when the herd leaves the noise range of the UAV for a certain distance, the herd decelerates. At this time, the UAV is driven to continue diving at the tail of the herd to drive the cattle. The human-machine drive direction moves slowly. When the UAV equipped with the high-altitude megaphone drives the cattle at the tail of the herd at a flying height of 2 m, the movement of the cattle is more stable. The herdsmen shout to the cattle through the walkie-talkie, and the UAV is able to drive the direction of movement. After comparing the four groups of UAV cattle herding experiments, it was found that the cattle were in the best movement state when the UAV drove the herd in the evening. Herdsmen usually drive the cattle back to the bullpen around 6 pm. The cattle have formed a biological clock, and at this time, the drone will move towards the target direction after driving the herd for a short time.

Table 5 Experiment of herding cattle with UAV

Experimental subjects	Experiment time	Coordinate	Number of livestock	Whether the UAV carries a payload (UAV megaphone)	Flying height /m	UAV driving method and process	UAV herding cattle effect
Cattle	2020.08.24 15:15	119.946,2 49.331,7	17	No	10	The UAV flew to the center of the cattle without a megaphone, and dived in the direction of the target drive	The cattle close to the UAV stop moving and watch the UAV, and move slowly away from the UAV when the UAV dives down; the cattle response time is long, the movement state is chaotic, and the direction of the moving target is not clear
Cattle	2020.08.24 16:07	119.9414 49.3243	16	Yes	10	The UAV is equipped with a megaphone to fly to the center of the cattle, and swoops to drive the cattle away with the help of cattlesmen's shouting	Some cattle individuals stopped exercising to watch the UAV, while the rest of the cattle moved slowly, with long reaction time, chaotic and irregular movement status, and unclear movement target direction
Cattle	2020.08.25 18:08	119.8926 49.3095	50	No	2	The UAV flew to the tail of the cattle without a megaphone and dived in the direction of the cattle to drive it away	The individuals at the tail of the cattle move away from the UAV, with slow movement speed and unresponsive response. The overall movement of the cattle is stable and the movement target is clear
Cattle	2020.08.27 18:30	119.8934 49.3100	50	Yes	2	The UAV was equipped with a megaphone and flew to the tail of the cattle in the bullpen. With the help of the herds men's shouting, it dived to drive the cattle out of the bullpen	Some individuals at the tail of the cattle watch the UAV. When the UAV dives, the cattle moves away from the UAV. The movement is slow, the response is slow, the movement state is stable, and the moving target direction is clear
Cattle	2020.08.31 09:12	119.8573 49.3015	57	No	5	The UAV flew to the tail of the cattle without a megaphone, and dived along the target direction; flew to the vicinity of the individual separated from the group, and dived and drove along the target direction	The tail herd moves towards the driving direction of the UAV, the movement speed was slow, the reaction time was long, and the movement state was chaotic; when a single individual drives away, the individual responds slowly, moves slowly, and the movement state is stable
Cattle	2020.08 31 17:50	119.9409 49.3151	23	Yes	6	The UAV flew to the tail of the cattle without a megaphone, and dived along the target direction; flew to the vicinity of the individual separated from the group, and dived and drove along the target direction	The tail cattle moves in the direction of unmanned driving, the movement speed is slow, the response is slow, and the movement state is stable; when a single individual drives, the individual responds quickly, moves fast, and the movement state is stable

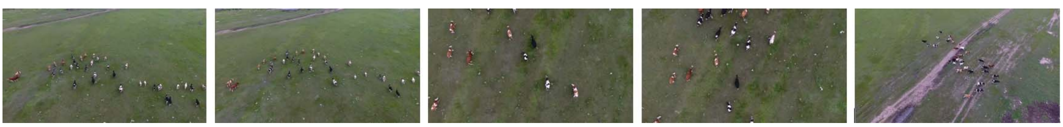

Figure 2 Experimental results of cattle herding by UAV

3.4 UAV Herding Donkey

A total of three groups of experiments were carried out by using a UAV with and without a megaphone and a UAV with a megaphone to drive the donkeys at the center and the tail of the donkeys, respectively. The effect of UAV herding is judged from three aspects: the reaction time of the donkey group, the movement state of the donkey group, and the accuracy of the movement direction of the donkey group. During the driving process, the flight speed and flight direction of the UAV are adjusted in real time according to the movement state of the donkey group. Table 6 and Figure 3 show the driving process and effect of the UAV donkey herding experiment.

Table 6 Experiment of using UAV for herding donkey

Experi-mental subjects	Experiment time	Coordi nate	Num-ber of lives-tock	Whether the UAV carries a payload (UAV megaphone)	Flying height /m	UAV driving method and process	UAV herding donkey effect
Donkey	2020.08.31 14:48	119.9383, 49.3153	15	No	5.5	The UAV flew to the center of the group of donkeys and dived in the direction of the movement of the female donkey in the group	When the UAV flies to the center of the donkey group, the donkeys disperse; when the UAV dives, the female donkey in the donkey group quickly moves closer and moves quickly along the flight direction of the UAV. The movement state is stable and orderly, and the group target direction clear
Donkey	2020.08.31 15:10	119.9372 49.3139	15	No	6	The UAV flew to the tail of the group of donkeys and swooped in the direction of the group's movement	A few individuals at the tail looked at the UAV, quickly approached the female donkey when the UAV dived, and moved quickly along the flight direction of the UAV. The movement state was stable and orderly, and the group target direction was clear
Donkey	2020.08.31 15:30	119.9339 49.3135	15	Yes	5	The UAV is equipped with a high-altitude megaphone to fly to the tail of the donkey group, and with the help of the herdsmen's shouting, it swoops and drives it along the movement direction of the donkey group	When the herdsmen shouted, the donkeys stared at the UAV, quickly approached when the UAV swooped, and quickly moved in the direction of the UAV's flight. The movement state was stable and orderly, and the group's target direction was clear

Figure 3 Experimental effect of UAV donkey grazing

Donkeys are docile, timid, sensitive to changes in the external environment, and run fast. When the UAV without a megaphone and the UAV with a megaphone swooped down to drive the donkeys, the donkeys quickly moved closer to the female donkey, and moved quickly in the direction of the UAV to drive along with the female donkey. In the third donkey herding experiment, when the UAV flew to the tail of the donkey group, individual individuals in the tail stopped and watched the UAV. After the herdsman shouted to the donkey group with the walkie-talkie to drive them away, the stray individuals quickly turned around and ran towards the female donkey. In the three donkey herding experiments, the donkeys were successfully driven to the water tank near by the animal pen.

3.5 Comparison of Grazing Effects of UAV for Different Livestock Species

Comparing the experiments of the UAV herding sheep, cattle, and donkeys, we find that the UAV grazing effect is good, and the effect of UAV driving sheep and donkey herds is better than that of driving cattle herds. Sheep and donkeys have a strong tendency to live in groups, and the actions of individuals are more easily affected by group actions, so the UAV can drive the entire herd by controlling key individuals in the herd. The order of the herd's response to external noise, ordered from strong to weak, are sheep, donkeys, and cattle. The herdsmen's shouting sounds can significantly stimulate and affect the actions of the sheep and donkeys, while the cattle herds have a strong anti-interference ability to the sounds. In the process of shepherding, the flock has an adaptation process to the UAV driving. During the period from when the UAV begins to descend within the audible range of the flock, the flock will quickly disperse towards a certain direction due to the interference of noise, running in an uncertain direction. After the flock is familiar with the noise of the UAV, it is best to drive the sheep from one end of the flock at a flying height of about 15 m, and in the case of the herdsmen's shouting assistance; the driving effect is clearly better than the driving effect of using UAV alone. In addition, there was no difference in the repelling effect of sheep of different sizes. In the eight groups of experiments, the UAVs were successfully used to drive the flocks. The stability of the herd's movement, ordered from stable to least stable, are donkeys, sheep, and cattle. In the process of the UAV driving the herd, the movement of the donkeys is the most stable, and the young donkeys always move around the female donkey; the sheep will quickly gather together and move in a certain direction after being disturbed by the external sound, and occasionally run away. Their scattering is divided into two parts, and after a little driving, they will quickly gather again. When the cattle are being driven away, some individuals move slowly, and the overall position is relatively scattered, and the movement speed is not coordinated. To ensure the movement of the cattle in the driving direction, the assistance of herdsmen or shepherd dogs is often needed.

The donkey herding experiment is special. First, there are few donkey herders in the Hulunbuir grassland. Second, the donkey group of the experimental subjects is a special group composed of female donkeys and their cubs. The behavior of this group is greatly affected by the actions of the female donkeys. After the experiments, it was found that the female donkey is sensitive to the UAV and herdsmen's voices. During the driving process, the cubs moved around the female donkey. The movement status and direction of the donkeys performed well with the help of the herdsmen's shouting. The response of the herd to the noise of the UAV is weak. When using the UAV to drive the herd, the UAV's trajectory needs to be adjusted to be about 2–3 m away from the herd. Finally, in the process of expulsion, it is necessary to adjust the UAV's position in time according to the individual response.

4 Issues and Challenges of UAV Grazing Applications

UAVs are highly agile in the air, and UAVs with high-resolution cameras can help herders understand the conditions of their herds in pastoral areas. There have been many cases of using UAVs for grazing, in China and abroad, and their effect on grazing is positive. However, some problems and challenges remain in the application of UAV grazing in grasslands.

(1) The degree of automation of UAV grazing in grassland pastures is insufficient. UAVs are easy to operate and flexible to use, but in the grazing process, herders still need to actively control the UAV to find herds, which is highly dependent on herdsmen. Scholars have developed target recognition and tracking algorithms based on the UAV operating platform. Still, the tracking system has not been integrated and applied, and the reliability of automatic tracking and recognition has yet to be tested.

(2) The battery life of UAVs needs to be improved. Due to the limitation of the maximum weight of the UAV itself, the specifications of battery are limited to a certain range. Taking the DJI UAV as an example, the maximum endurance time of a no-load take-off is about 30 minutes. At present, the battery charging time for a UAV on the market is generally long. To ensure an ample operating time for the UAV, it is necessary to carry multiple spare batteries. In addition, when the pastoral area is large, it is necessary to ride a motorcycle to the driving place. The problem of optimizing the battery solution and prolonging the single operation

time of the UAV needs to be urgently addressed.

(3) The accuracy and stability of the UAV positioning system are insufficient. At present, UAV positioning and navigation mainly adopt GPS and Beidou dual-star mode. Major UAV manufacturers have optimized the cruise algorithm based on the navigation satellite positioning system so that the positioning accuracy can reach the meter level. However, when the UAV operates in high latitudes, it is easily affected by objective conditions such as terrain and weather. The interference of the navigation satellite signal causes the UAV to deviate from the predetermined orbit. The problem of insufficient accuracy and stability needs to be resolved.

(4) Communication capabilities such as UAV image transmission need to be improved. The UAV and the ground control terminal mainly carry out image transmission (image transmission), data transmission (data transmission), and remote control interaction. Most UAVs on the market have a maximum signal transmission distance of 4–7 km without signal occlusion. However, in many complex situations, the actual signal transmission distance cannot reach this standard and cannot meet the needs of long-distance grazing. In addition, the current network base station cannot completely cover the entire flight airspace, and the long-distance grazing of the UAV is prone to the loss of the image transmission signal and the delay of the remote control of the UAV on the ground. Enhancing the data transmission capability and signal transmission capability of UAVs is a key problem that limits UAV grazing.

(5) The massive geographic data byproducts generated in the UAV grazing process are not fully utilized. A UAV equipped with high-resolution optical cameras is an important tool for collecting near-surface topographic data in multiple disciplines such as geography, grassland science, and ecology. A UAV will generate a large amount of surface image data in the grazing and driving processes, herd searching, and herd monitoring. These data include not only attribute information such as geographic location but also information such as surface morphology and object type. These massive images can be systematically organized and filtered and can be used as a data source for grassland status assessment and detection in pastoral areas, which is of great significance. At present, the massive image information produced by the UAV grazing process lacks effective management methods, and how to organize and establish an image database remains to be studied.

5 Prospect

UAVs are an important tool to automate grazing, and they are playing an increasingly important role in grassland grazing management. This paper introduces the related technologies and development status of UAV grazing, summarizes the application of UAV in grazing at home and abroad, and analyzes the effect and feasibility of UAV grazing in combination with the Hulunbuir UAV grazing livestock experiment. In recent years, researchers have explored a series of innovative technologies to meet the high demands of UAV hardware in complex scenarios. With the in-depth research and promotion of new technologies such as artificial intelligence, new batteries, and 5G communications, the application of UAVs in grassland grazing management will enter a new development stage, and the realization of highly automated UAV grazing is just around the corner.

(1) Artificial intelligence helps UAV grazing to develop towards high automation. In recent years, the application and practice of target tracking algorithms have gradually matured, and a large number of studies have shown the efficiency and feasibility of convolutional neural networks in the field of image recognition and target tracking. UAV technology research with an intelligent tracking module will be a bright spot.

(2) The livestock monitoring system promotes the improvement of the soft power of UAV grazing. Domestic and foreign researchers have done much research concerning the

identification of ground wildlife based on UAV detection and have achieved fruitful results. Wang *et al*. developed a real-time herd identification system based on the UAV platform, which realized online identification, counting, and weight estimation of livestock with an accuracy of over 90%. For the identification of dense herds, the error is relatively large. In the future, by enriching the data of the sample database and improving the model, it will be more accurate to realize the low-error identification of livestock and assist herdsmen in realizing the automatic management of livestock.

(3) The new battery material achieves the ultra-long battery life required by the UAV. In so far as the existing small fixed-wing and multi-rotor UAVs on the market are concerned, the power sources are mainly lithium-ion power batteries, and the bipolar materials of the batteries play a decisive role in performance and cost. Silicon carbon composite material is a new type of electrode material, and major lithium battery manufacturers have begun to study it. Some manufacturers try to solve the problem of volume expansion, strong liquid absorption ability, and the cycle time of silicon-carbon composite material during charging and discharging through silicon-carbon coating and doping. Regarding the problem of poor longevity, some achievements have been made. As a future negative electrode material, the theoretical gram capacity of silicon-carbon composite material is about 4200 mAh/g, which is more than 10 times higher than the 372 mAh/g of a negative graphite electrode. This technological advance will extend the UAVs flight time. In addition, the application of nanotubes and aerogel batteries will also greatly improve the long-term operation capabilities of UAVs.

(4) The 5G communication module assists the UAV in being the “eye of the sky” for herdsmen. The biggest feature of 5G communication is its large bandwidth. In theory, the bandwidth of 5G can reach more than 20 Gbps. In terms of reducing signal interference, 5G can use the laying of large-scale antennas and narrow beams to serve users, thereby reducing mutual interference in the user area and providing a reliable guarantee for low-altitude communication of UAV. The 5G ubiquitous network can improve the flight distance and positioning accuracy and solve the limitation of UAV control distance. In addition, the 5G network has the characteristics of ultra-low latency and can provide millisecond-level transmission delay, which means that a UAV with 5G communication capabilities can respond faster to ground control commands and can avoid complex terrain during grazing. The barrier capability is further improved.

(5) A geospatial data cloud master helps to build a big data system for UAV grassland monitoring. A UAV equipped with high-resolution visible light sensors can spontaneously obtain ground orthophotos during grazing. After many applications in grassland animal husbandry, a UAV will produce a large amount of grassland image data. These massive data are arranged in a certain format and organized way before being uploaded to the cloud synchronously, which can form the grassland big data based on the geospatial data cloud. After image stitching, data information mining, etc., a series of multi-period grassland near-ground remote sensing images are generated.

UAVs can establish strong support for grassland monitoring and sustainable development of animal husbandry and, at the same time, assist the government in formulating grassland development policies.

(6) The ground monitoring system is combined with the UAV to build an air-ground integrated animal husbandry detection platform. The ground monitoring system (such as a dome camera) has the function of automatic tracking of regional targets and accurate tracking of locking, which can realize large-scale chain monitoring and has great application potential in grassland pastlure management and grazing. Compared with a UAV, the high-definition camera monitoring system has the advantages of all-weather, all-day, long-term fixed-point monitoring, etc., which can make up for the lack of remote monitoring of a UAV to a certain extent. Combining the UAV with the ground monitoring system can

achieve regional management of the pastoral area, monitor the movement status of the herd through the camera, and use the UAV to monitor or drive some “problem” individuals alone, forming a dynamic and static combination of an air-ground integrated animal husbandry detection system.

Author Contributions

Wang, D. L. designed the algorithms of dataset and organized UAV grazing experiments. Zhang, A. Y. contributed to the data processing and wrote the data paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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