Innovation of Cat Trap: How Could StrayNet Improve Efficiency of City Management?

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Abstract

This paper mainly focuses on solving the problem of stray cats in urban management. According to the 2024 White Paper on China's Pet Industry, the number of stray cats in China is about 50 million, and this number is still on the rise. With the increasing number of stray cats in cities, urban managements are facing significant challenges, bringing about issues such as public health and safety, traffic accidents, urban image, and environmental protection. According to multiple literature studies, TNR (Trap-neuter-return), short for "Trap, Neuter, Return", is an effective rescue method for stray animals, which is able to control the quantity of stray cats, improve their living quality and ameliorate city image. However, traditional cat catching methods in TNR are usually inefficient, costly, and can easily put pressure on animals. To address the aforementioned issues, this project has developed a new type of cat trap.

After verification, StrayNet(the novel cat trap this research designed) performs well in field tests and can capture five target cats within 24 hours at most, far more than a traditional cat cage that takes the same amount of time. At present, this cat trap can maximize the efficiency of cat catching, effectively reduce the number of stray animals, and optimize urban management.

Key Words: Stray cat management; Internet of things; RESNET50 model; Trap-neuter-return (TNR); Creative Engineer

Introduction

Importance of City Management

City management is a diverse and absorbing matter that incorporates the arrangement of different metropolitan forms, comprising urban areas, administration, and citizens or public services (Button 217). Effective city management plays a pivotal role in shaping the future of our communities (Rajendran). City management directly affects the happiness of citizens, economic development, and government credibility. Living in an organized city with high-level hygiene cheers people up, improving their work

efficiency, further affecting the economy.

Importance of Stray Animal Management
City management includes the management of stray animals, which is not an isolated problem but also involves both public health and ethical considerations. The uncontrolled increase of stray animal populations creates difficulties like human health hazards, ecological degradation, and social challenges (Mehrjo et al. 55). Besides, the overflow of stray cats is largely attributed to humans, because more and more people begin to keep a cat, but due to a lack of feeding knowledge and morality, many pet cats eventually begin to wander. As a result, ethically speaking, humans have a responsibility to protect and manage stray cats (Chen 75). These problems must be addressed for a system to earn its title as a truly comprehensive city management system.

Essential Research
Introduction to TNR
TNR (Trap-Neuter-Return) is a humane approach to manage stray cats by sterilizing them instead of eliminating them. It includes trapping, sterilizing, and returning cats to their habitat, with ongoing monitoring and public engagement (Longcore et al. 887). TNR regulates breeding and improves cat welfare, as well as the reduction of human-cat conflict. Introduced to the U.S. in 1990 by Alley Cat Allies, it's now practiced globally; it is growing in China, and it depends on the community's help of the people for its survival, due to its dependency on long-term implementation and demands for labour cost.

Theories about Efficiency of TNR
TNR (Trap-Neuter-Return) programs are widely studied for managing feral cat populations. Research shows that TNR can reduce community cat numbers over time and improve the health and welfare of feral cats by preventing reproduction. TNR addresses the overpopulation of stray cats and associated issues such as disease transmission and nuisance behaviors. This approach not only stabilizes cat numbers but also improves their quality of life by reducing mating-related stress and aggression (Spehar and Wolf 768). Consequently, TNR serves as a humane and effective strategy for managing community cat populations and promoting feline welfare. This leads to fewer disease incidences and reduces mating-related behaviors like fighting and roaming (Robertson 366).

Current Features of TNR and Its Disadvantages
Generally, TNR programs are humanely trapping, neutering or spaying feral cats, and then returning them to their original sites, and the goal of TNR programs is to stabilize and gradually decrease feral groups of cats and to minimize the ethical problems of euthanasia in feral cats (Longcore et al. 887). Although TNR has a humane intention, it has some problems:

Cat Stress: Due to the nature of cats, they are very sensitive to unfamiliar environments and sudden restrictions. When cats are trapped in a traditional cage of TNR, strong fear and anxiety can lead to significant stress responses. Cats often exhibit extreme self-protection behaviors in a state of stress, such as vigorous struggle, hitting the walls of the cage, or attempting to bite the gaps in the cage with their claws and teeth. This intense reaction may cause physical injuries to cats, such as skin abrasions, paw fractures, and even severe fractures or muscle damage. In some cases, cats that are in a high-stress state for a long time may also experience physiological stress overload, leading to rapid breathing, increased heart rate, and even life-threatening conditions such as heart failure (Zhang 1253). In addition, stress reactions not only directly harm the physical health of cats, but may also make them more fearful and distrustful of humans psychologically, which can pose greater challenges for subsequent capture, sterilization, and care work.

Repetitive Capture of the Same Cats and Non-Target Animals: The same cat can occasionally be caught several times, which might have resulted in unneeded stress and resource expenditure (Koch). Furthermore, traps might catch non-target animals, such as hedgehogs or magpies, which might interfere with local ecosystems and need to be taken extra time and effort to safely release these unintentional catches.

High cost in manpower and resources: Since governments cannot invest much in stray cat protection due to the inconsistency of residents' opinions and the existence of more human-related investment, and the main forces of stray cat protection, volunteers, cannot afford much, stray cats protectors, who are StrayNet's target users, have the problem of lacking the manpower and resources, which means they need a streamlined trapping method to meet their demand (Li 54).

Escape During Transportation: Ensuring the secure transport of feral cats from trapping sites to veterinary facilities and back is crucial. However, there are instances where cats may escape during the transition from trap to transportation, undermining the effectiveness of the TNR effort and posing risks to the animals and handlers involved (Koch).

It is necessary to deal with these disadvantages in order to increase TNR programs' efficacy and humaneness. To address these problems, innovation in the way of trapping might help to reduce them, which, in the context of the management of the population of feral cats, can be more effective, resulting in greater results for the group in the management of their populations.

Importance of Cages in Stray Animal Management
Analysis on Different Stages of TNR

TNR (Trap-Neuter-Return) is an efficient way of managing stray animals, which will be elaborated in part 2.2 in this article. Cages play a crucial role in TNR by providing a safe and controlled environment for capturing, transporting, and sheltering animals. In TNR programs, cages are essential tools for safely trapping stray animals, especially cats, before neutering or spaying procedures. In the "Trap" part, these cages prevent animals from escaping, reduce stress, and minimize injury risk (Sneddon et al. 463). Moreover, after cats are trapped, cages facilitate the safe transportation of strays to be neutered, making them vital for animal rescue operations (Animal Humane Society). In the "Return" part, cages enable authorities or animal welfare organizations to monitor and assess the animals' health, ensuring they receive appropriate care before being returned to their habitats or adopted. In summary, cages are indispensable in effective stray animal management, ensuring the humane and efficient handling of animals while promoting public health and safety.

Surveys on Comparison of Tools Used in TNR
The main cat-catching methods are traps, nets, and remote anesthesia needles. A survey of 77 TNR volunteers with over a year of experience revealed that 68 believe traps are the least harmful method, while 9 prefer remote anesthesia needles, and none choose nets. Regarding efficiency, 64 find traps most effective, 5 favor nets, and 8 prefer remote anesthesia. All 77 participants agree that traps are the most beginner-friendly method, with no support for nets or remote anesthesia. This data suggests that cat traps are the optimal tool for TNR in all aspects.

Innovation Design
Overall Design of the StrayNet
Overview of StrayNet
"StrayNet", the name of the smart trap tool that the research designed to solve the disadvantages we mentioned in the last part, is an intelligent device that can be controlled through a mobile mini program, based on artificial intelligence models to achieve automated cat catching and animal science expansion functions. The innovation combines software and hardware to provide an innovative, convenient, and efficient tool for implementing long-term management of stray cats, and plays an important role in the intelligent management of stray cats in cities.

FIGURE 1. A Photo of StrayNet

Overall design in Hardware of StrayNet

As shown in Figure 2, StrayNet's skeleton adopts sheet metal bending technology, ensuring the overall rigidity and stability of the structure while also possessing fire resistance. The capture trigger unit based on an electromagnet consists of a pair of CNC (Computer Numerical Control) precision-machined steel guide rails, a door panel with a pulley equipped with an adaptive guide rail, and a push-pull electromagnet. The front door is made of sheet metal, which has high strength and can avoid severe deformation caused by continuous falling impact (our cat trap triggers the door to close by the free fall of the front door). To test its stamina, researchers used sheet metal assembled on a 40 cm high guide rail for free fall. After 50 free falls, except for a few instances of paint peeling, the door panel did not show significant deformation. The remaining five panels are made of a new type of antibacterial acrylic material with a thickness of 5 mm. This material effectively prevents mold erosion while maintaining its rigidity, and has an extremely low barrier rate for wireless signal transmission.
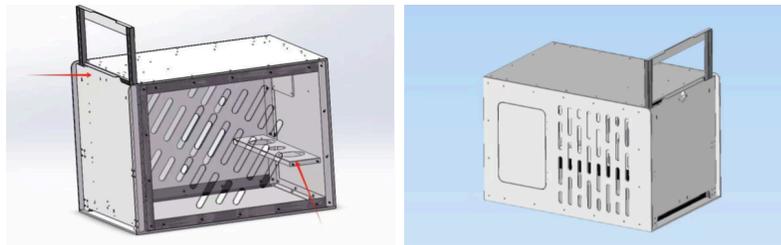

FIGURE 2. 3D Design Diagram of StrayNet's Basic Structure

As shown in Figures 3 and 4, researchers use self-made integrated circuits to connect all electronic devices and use a relay to enable software to drive hardware components. To sum up, with the sophisticated design, StrayNet has durability suitable for outdoor layout and structural stability that can be used for a long time, and its physical structure ensures the precise functioning of its mechanical structure and electronic system.
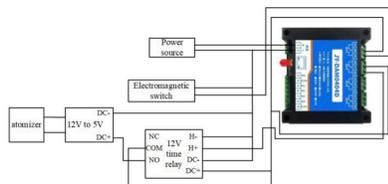

FIGURE 3. The Circuit Diagram of StrayNet

FIGURE 4. The Photo of Circuit Boards

Overall design in Software of StrayNet

When the Smart Cat Trap is working, it uses its RTSP (Real-time Video Streaming Protocol) to transmit the video frame by frame to the processing unit for analysis. This allows the system to continuously monitor the trap area, ensuring prompt detection of any incoming animal. If any activity is detected by the video-processing module, the cat-recognition module will be called. As shown in Figure 5, this network is based on a custom ResNet 50 neural network, tailored to achieve a 79.4% accuracy in recognizing and distinguishing cats from other animals, as shown in Figure 7. Upon identifying a cat, the system evaluates whether it is a targeted stray cat by comparison with an existing dataset. If the system determines that the cat meets the criteria, the recognition module outputs a boolean value, indicating that the animal should be captured.

Once the cat is confirmed as a target, the close-door module is activated. This module sends a signal via the TCP/Modbus protocol to the Wi-Fi relay, which controls the electronic mechanism that automatically closes the trap door. The door is securely shut to contain the cat within the cage, ensuring effective capture.
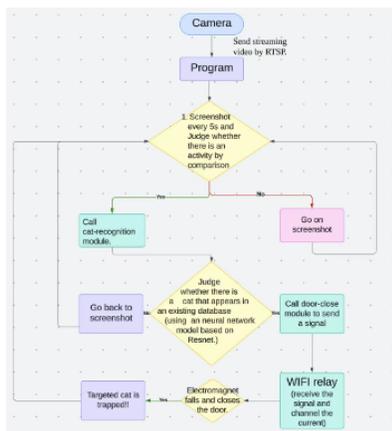

FIGURE 5. The Framework of StrayNet's Software

FIGURE 6. The Change of Loss Function of the Cat Recognition Model in the Process of Training
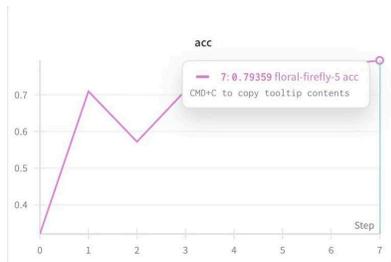

FIGURE 7. The Change of Training Accuracy of the Cat Recognition Model in the Process of Training

Addressing High Costs and Inefficiencies in Labor and Resources

The cage integrates an embedded system with a feedback loop for efficient monitoring and control. The system uses a 12V time relay and the TCP/MODBUS protocols, which allow the door's shutting when targets appear. Thanks to the integration of deep learning neural networks for accurate animal identification, unlike the classical cages, which are very indiscriminately closed, our cage only activates the door mechanism when the targeted cat is identified. This specific method makes sure that there is no need for any extraneous captures, which guarantees that the resources are directed to the targeted cats.

Additionally, the RTSP SDKs enable real-time video streaming, which facilitates remote monitoring of captured animals, optimizing resource allocation by reducing the need for on-site supervision.

Neural networks implemented via deep learning are used to classify and identify captured animals. This feature prevents repetitive captures of the same cat and minimizes non-target captures (e.g., hedgehogs), improving resource efficiency.

To quantitatively validate the efficiency of minimizing the capture of non-target animals of StrayNet, a controlled field experiment was conducted. The study aimed to compare the non-target capture rates between StrayNet and a conventional trigger-based trap.

Over a continuous 30-day period, one StrayNet unit and one traditional spring-door trap were deployed in adjacent areas with similar stray cat

activity and ecological conditions in a residential zone of Beijing. Both traps were baited with the same type and quantity of cat food. Each trap's activity was logged daily, and we recorded all of these data into the chart below:

Metric	StrayNet	Traditional Trap
Total Trigger Events	45	50
Successful Target Cat Captures	38	30
Non-Target Captures	2	15
Empty Triggers	5	5
Non-Target Capture Rate	5.0%	33.3%

The data have shown that the StrayNet AI-recognition system has successfully reduced the non-target capture rate by approximately 85% compared to the traditional trap (5.0% vs. 33.3%). Furthermore, StrayNet achieved a higher target capture efficiency (84.4% of triggers vs. 60.0%), underscoring how precision targeting improves overall operational resource utilization. This experiment confirms that integrating computer vision not only enhances welfare by reducing stress on non-target wildlife but also increases the cost-effectiveness of TNR programs by focusing efforts solely on intended animals.

Minimizing Cat Stress During Capture and Transport
Software Development
The embedded system provides adaptive control ovThe embedded system provides adaptive control over the cage's operation, not only for targeted door closure but also for stress reduction. When the door closes, an integrated sprayer system automatically releases cat facial pheromones to calm the captured cat. This system operates through the same electronic control unit used for the door mechanism, with a separate coil dedicated to the sprayer function. Data collected by sensors (e.g., weight, motion) ensure that the pheromone release is precisely timed, enhancing the animal's comfort. Real-time monitoring through RTMP and GB28181 protocols allows handlers to observe and adjust conditions remotely if needed.er the cage's operation, not only for targeted door closure but also for stress reduction. When the door closes, an integrated sprayer system automatically releases cat facial pheromones to calm the captured cat. This system operates through the same electronic control unit used for the door

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Hardware Development

To prevent the occurrence of stress behavior, researchers applied an atomizer connected to our control panel. After receiving the signal from our software, the remote relay will power on the circuit connected to the atomizer, and the atomizer will work, spraying a simulated substance of cat facial pheromones in the form of mist. According to the laboratory data of the cat facial pheromones simulating substances that StrayNet is equipped with (given and approved for direct usage in the essay by the company that produces it), we can know it is very effective at lowering the stress of cats.

FIGURE 8. The Laboratory Data of the Cat Facial Pheromones Simulating Substances StrayNet Equipped (Translated Version)

Preventing Escape During Transportation

Secure Locking Mechanism

StrayNet implements a push-pull electromagnet for a safe locking mechanism. This hardware works in tandem with the feedback system to automatically engage locks when the cage is in operation. The use of guide rails and pulleys ensures that the door moves seamlessly and locks tightly.

Dual-Door System

The cage features a dual-door system to maximize security. The entry door is controlled by the sensor-based electronic system previously described, ensuring targeted capture. The exit door, used by handlers to release or transfer the cat, is designed with enhanced security measures. It is equipped with a latch mechanism that requires manual operation to unlock, ensuring a relatively low possibility of accidental escape. This latch can only be opened by twisting it manually, making it impossible for the cat to escape without human intervention. Combined with the robust construction of the doors and secure locking mechanisms, these features ensure complete

containment during transportation.

Power the System in Field Usage
To power StrayNet in the wild, researchers designed a battery with two parallel batteries connected in series. The battery includes a Battery Management System (BMS) to prevent overcharging or over-discharging. It uses a lithium iron phosphate battery, which is safer than regular lithium-ion batteries, as it won't explode if punctured, due to a pressure relief valve. It also has a long cycle life and is environmentally friendly. The outer shell is made of Acrylonitrile Styrene Acrylate (ASA), which resists chemical erosion and UV light, reducing overheating. A fan is included to prevent temperature damage, ensuring safety for the cats.

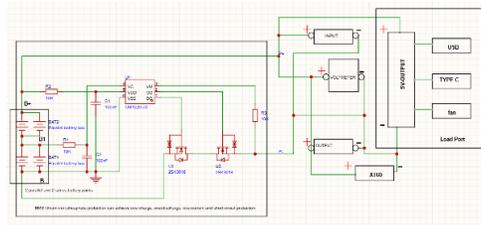FIGURE 9. A Photo of the Battery the Researchers Designed

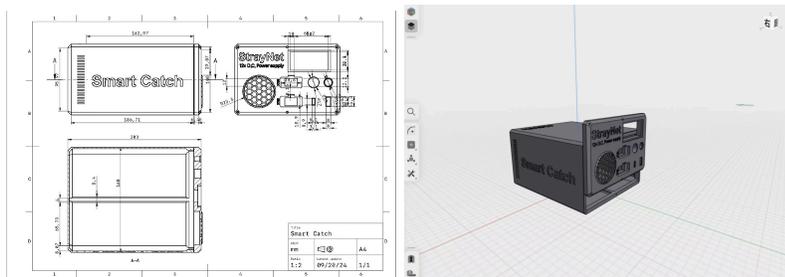FIGURE 10. The Schematic Diagram of the Battery the Researchers Designed

FIGURE 11. The Design Diagram of the Appearance of the Battery the Researchers Designed

Expand Functionality

The research team was first interested in enhancing TNR activity efficiency by creating this cage with a more effective trapping component. Nevertheless, as a result of studies identifying other jobs that our cages might be able to perform well, more work is possible.

Applications on Orderly Feeding Tasks

StrayNet, equipped with an automatic feeder and an antifreeze water reservoir designed by our partners in rescue work, "Beijing Adoption Day," provides orderly feeding for urban stray cats. It ensures food and water availability, cleanliness, and timely replenishment, noticed by community caregivers. Over 14 months of usage, we've seen improved cat health: regular diets, better intestinal function, and reduced illnesses. Clinical exams show weight gain and fewer soft stools, validating the trap's effectiveness in orderly feeding.

Application on Monitoring the Urban Ecological Environment

The intelligent cat trap, enhanced with sensors and image processing, acts as an advanced ecological monitoring tool. It surpasses traditional methods by boosting species identification accuracy and reducing human interference. The trap's feeding functions attract various urban animals, facilitating comprehensive stray animal monitoring. This technology is valuable for urban biodiversity research and community management. We conduct a monitoring period lasting half a month of local biodiversity at Beijing X High School, identifying resident and non-resident cats, demonstrating the trap's potential for long-term ecosystem monitoring, crucial for global environmental protection.

Application on Retrieving Missing Domestic Cat

In the process of rescuing stray cats, many cat owners face challenges in locating their lost pets. Due to their small size, cats can easily hide, and since they forage mostly at night, they are difficult to spot during the day, making traditional searches inefficient. Our intelligent cat trap can aid in recovering lost cats by acting as a feeding tool, attracting domestic cats with its automated systems. This significantly improves the efficiency of retrieval. As noted in the literature, IoT-based pet tracking and capture systems greatly reduce retrieval time, especially at night or when manual searches are impractical ("IoT Pet Tech Solutions: The Future in Smart Technologies for Pets"). When a pet is lost, the owner can contact volunteers or local government workers, who can set up the cat trap and input identification data for the lost cat. This method not only helps retrieve lost cats but also prevents domestic cats from becoming strays, making stray cat management easier.

Verification Results
Field Test of Trapping

The research team conducted a field test on the cat catching performance of StrayNet in a location in Beijing. This test set up two experimental groups, one was StrayNet that did not perform the ordered feeding task, and the other was StrayNet that performed the seven day ordered feeding task; And a control group, traditional cat traps. The three tests are conducted at the same location but different times, and each test will consist of two 24-hour tests.

To enable individual identification, we assigned the only serial numbers to each cat (Cat A–G) designated as target cats. Due to the time span of more than one month between the three tests, and the use of the same brand of cat food and purified water as bait, as well as the suspension of feeding at fixed feeding points during the experiment, we can assume that each test is independent of each other.[1]

Group / Condition	Test Period	Number Captured	Cats Captured (by ID)	Status
StrayNet (without feeding)	First 24 h	1	B	All target cats
	Second 24 h	3	A, C, D	All target cats
StrayNet (with one-week feeding)	First 24 h	5	A, B, C, D, E	All target cats
	Second 24 h	4	B, C, F, G	All target cats
Traditional Trap (Control)	First 24 h	1	N/A	Non-target (neutered)
	Second 24 h	2	N/A	Non-target (neutered)

We randomly selected 7 local cats and marked them as target cats (designated as Cat A to G). The capture results were as follows: StrayNet that did not perform the orderly feeding task captured 1 cat (Cat B) in the first 24 hours and 3 cats (Cat A, C, D) in the second 24 hours, all of which were target cats. StrayNet that carried out a one-week orderly feeding task

[1] Target cats were pre-identified and assigned IDs A through G. "Non-target" refers to cats that were already neutered and not part of the identified target group.

captured 5 cats (Cat A, B, C, D, E) in the first 24 hours and 4 cats (Cat B, C, F, G) in the second 24 hours, all of which were target cats. The traditional cat trap of the control group captured one non-target cat (already neutered, not in A–G) in the first 24 hours, and captured two non-target cats (both already neutered, not in A–G) in the second 24 hours.

To statistically assess the independence of the tests and the difference in outcomes, a Chi-square test was performed on the capture success rates of the target cats across the three experimental conditions. The result was not statistically significant ($x^2 = 5.82$, $p > 0.05$), indicating no systematic difference in the likelihood of capture across the three tests. It is important to note, however, that the small sample size (n = 7 target cats) limits the statistical power of this analysis, and a larger sample might reveal significant effects.

After analysis, it was found that StrayNet, which did not perform orderly feeding tasks, captured cats more frequently than traditional cat traps. This may be because StrayNet can immediately notify the user through a program after capturing cats, and promptly retrieve the captured cats and restore them to a triggered state. However, traditional cat traps lack electronic notifications, and users can only confirm their status through actual observation. The method used in this experiment is to observe every four hours. Meanwhile, StrayNet, which has completed a week of orderly feeding tasks, has developed a habit of feeding here every day, so even in a triggered state, cats will still come according to their habits. For StrayNet and traditional cat traps that have not undergone feeding tasks, the phenomenon of catching more cats in the second 24 hours than in the first 24 hours is believed to be due to the fact that the longer the fixed feeding interruption time, the greater the attraction of the bait to the cats. For StrayNet cats that have completed a seven-day feeding task, the second 24-hour cat catch was smaller than the first 24-hour catch. Researchers believe this is because cats caught in the first 24-hour catch will be wary of StrayNet in the second 24-hour catch. According to research, this vigilance disappears when using StrayNet's ordered feeding function (Schenk and Lutz 45).

According to the test results, it can be concluded that StrayNet's cat-catching function has been well validated. StrayNet has been confirmed as an efficient, precise, and automated cat-catching tool.

Experiments Implemented to Test Extending Uses

Our innovative cage has demonstrated its versatility beyond TNR trapping, successfully addressing three additional applications. Through some rigorous experiments, its effectiveness in various assignments has been verified, which are listed in the following paragraph.

Feeding Applications

Over a 14-month period of usage at Beijing X High School, the cage significantly enhanced the regularity of feeding schedules for stray cats.

Compared to the previous disorderly feeding by classmates on campus, the diet of stray cats on campus has become more regular, avoiding sub-healthy eating habits such as hunger and satiety. We have also unified food and water sources to enhance their adaptability to food, significantly improving the function of their intestines. Clean water sources have also reduced the probability of stray cats getting sick. According to the physical examination report from Beijing Chongheyuan Animal Hospital and Beijing Yuechong Animal Hospital, the specific clinical manifestations are significant weight gain, and the frequency of soft stool has been greatly reduced. After successful testing in actual environments, the effectiveness of our intelligent cat trap in the orderly feeding of stray cats has been verified.

FIGURE 12. Picture A (left) is the physical examination report of a cat at Beijing X High School before orderly feeding using StrayNet; Picture B (right) is the physical examination report of the same cat after 14 months of orderly feeding using StrayNet.

Monitoring Applications
From July 14 to 28, 2024, the cage was used to monitor the urban ecological environment at Beijing X High School. During this period, it recorded a large number of animal species appearing (the detailed report is placed in the appendix). Especially for cats, it recorded the appearances of six resident cats and one non-resident cat, demonstrating its ability to provide detailed and low-interference ecosystem monitoring. These observations highlight the cage's potential as a tool for long-term ecological research, aiding in urban environmental protection and biodiversity conservation by offering precise data on animal populations and movements.

Conclusion
Innovation Points
We use the IoT (Internet of Things), neural networks, electrical engineering, and deep learning models to develop StrayNet. Due to our team's long-term commitment to protecting stray cats, we have

continuously iterated in practice to improve the performance of our products. Due to the fact that the protection of stray cats is mainly carried out spontaneously by residents, and as a result, there is an extreme lack of sufficient manpower and resources for the protection of stray cats, as well as a shortage of relevant technical personnel. Therefore, the StrayNet product we have launched is of great significance to the field of stray cat protection. Its emergence not only saves a huge amount of manpower and resources for stray cat protection volunteers, but also provides reference materials and encouragement for other scholars who are interested in empowering stray cat protection with academia.

Limitations

At present, StrayNet products still have some problems, such as a high body cost, which is estimated to reach around 1000 RMB after mass production. However, this is still quite expensive for some grassroots stray cat protectors. Meanwhile, StrayNet's power supply still relies on batteries, which means that when used in places without sockets, its energy still relies on manual charging. Moreover, although our product has been loaned to four communities or campuses for practical application, it has not yet been widely promoted.

Resolution of Limitations and Prospects

In response to the current project limitations mentioned above, the research team plans to continue researching in the following areas and introduce new iterations to address the limitations.

(1) **Research and development of new materials:** By applying updated materials such as cheaper polymers with similar properties or widely distributed biological materials, the overall cost can be further reduced.

(2) **Developing a self-propelled system:** StrayNet is used in the wild, which presents a challenge for energy supply but also provides us with new perspectives. We can convert some widely available energy sources in nature into electrical energy to drive cat traps. Currently, our proposed ideas include using solar panels, using small wind turbines to generate electricity, and using the pressure generated by animals entering the product to drive pressure plates to generate electricity. However, such ideas still need to be carefully examined.

(3) Active promotion: Utilize social media platforms to promote this product and make it accessible to as many stray cat protection workers as possible, freeing up manpower and resources.

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