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Construction Methods and Applications of Endangered Animal Digital Twin Models Based on Digital Technologies

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Abstract: *The application areas of digital twin technologies and models are extensive, including industrial manufacturing, energy management, transportation, healthcare, infrastructure, and urban planning. With the rapid development of digital technologies, the study of digital twin models for endangered animals has become increasingly significant. These models can better understand the ecological systems, behavioral habits, and population status of endangered animals, providing valuable insights for wildlife conservation. Moreover, digital twin models can serve as a novel and engaging tool for science popularization, drawing public attention to the issue of endangered animal protection, increasing public participation and engagement in conservation efforts, and collectively promoting endangered animal conservation. This article focuses on the application of constructing digital twin models for endangered animals and explores their wider applications in the field of animal protection.*

Keywords: *Digital Technologies, Digital twin, Digital Model of Endangered Animals*

1. The Concept of Digital Twin Models

A digital twin model is a technology that simulates real-world objects or processes using digital means. Its most fascinating aspect is not only presenting a dynamic and changing visual information flow consistent with the real world but also predicting potential problems through data collection, rule analysis, self-learning, and completing risk avoidance in advance. This is what we often refer to as optimizing the performance and efficiency of real-world objects or processes based on the analysis results of digital models and providing decision support [1].

2. The Significant Role of Digital Twin Models in the Field of Endangered Animal Conservation

In the field of endangered animal conservation, digital twin models can help scientists gain a deeper understanding of animal ecosystems, behavior, and population status, providing accurate strategies for wildlife conservation. Real-time monitoring of animal populations and habitat conditions can greatly reduce the safety and cost of patrol personnel in protected areas. Additionally, by analyzing and mining data, digital twin models can predict changes in endangered animal populations, providing early warning information for conservation efforts and helping scientists to take protective measures in a timely manner, increasing the accuracy of decision support for conservation work.Digital twin models also help to evaluate the contributions of endangered animals to ecosystem services, such as climate regulation, water purification, and biodiversity conservation. The evaluation results can provide a basis for the formulation of conservation strategies and help achieve a balance between ecological protection and economic development. As a powerful tool for conservation education and ecotourism in the digital age, digital twin models can increase public awareness and participation in endangered animal conservation. Digital twin models can provide an open data platform to promote communication and collaboration among governments, research institutions, businesses, non-governmental organizations (NGOs), and the public. By sharing data, resources, and technology, all parties can work together to promote the development of endangered animal conservation [2-3].

In terms of application, digital twin models promote interdisciplinary research and can integrate

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knowledge from multiple disciplines such as biology, ecology, data science, and computer science, providing more comprehensive and in-depth theoretical support for endangered animal conservation. In practice, we have found that virtual reality can be used to visualize complex data, identify key issues and bottlenecks in endangered animal conservation, and thus allocate protection resources reasonably and improve the efficiency of conservation work. At the same time, digital twin models can be used as a novel and interesting science education tool to attract public attention to endangered animal conservation issues and increase public participation in conservation work, promoting the development of endangered animal conservation [4].

For example, combining digital twin models with virtual reality (VR) and augmented reality (AR) technology can provide the public with an immersive animal conservation education experience. Circus Roncalli in Germany has been widely praised for using holographic projections to replace live animals in its performances, becoming the world's first circus to use holographic projection technology. This represents the growing awareness of endangered animal conservation and the maturity of the public's acceptance of virtual digital entertainment. Meanwhile, this approach also reduces the incidents of animal injuries caused by satisfying the public's entertainment needs, such as the painful lesson of killer whales killing their trainers in recent years.

3. In Terms of Digital Technology for Endangered Animals, There are Several Aspects

Scientists and researchers have begun using 3D modeling and scanning technology to create digital models of animals. These models can help researchers better understand the physiological structure and ecological behavior of animals, providing strong support for conservation work. For example, some scientists are using 3D printing technology to replicate dinosaur fossils for more in-depth study of their habits and evolutionary processes.

Animal migration simulation: To better understand and protect animal migration behavior, scientists use tracking technology and geographic information systems (GIS) to create animal migration simulation models. Through these models, researchers can predict the migration paths of animals and develop more targeted measures for wildlife conservation.

Ecosystem models: Scientists and ecologists use computer simulation technology to create virtual ecosystem models to study the survival status of animals in specific environments. These models help predict the impact of environmental changes on animal populations, providing scientific basis for conservation work. For example, researchers predicted the future survival of polar animals (such as polar bears) by simulating the impact of global climate change.

Although these projects use digital technology to provide strong support for animal conservation and research, they are not strictly speaking virtual digital twins because they do not have the most important core element of digital twins: building a digital version of a physical object, a dynamic "clone" that must be a real-time dynamic mirror that can be detected. Currently, the construction of digital twins for endangered animals is still in a conceptual stage, and improving the accuracy of digital twin models for endangered animals has become the most pressing issue for many biologists, ecologists, computer experts, visual experts, animal protection organizations, and other stakeholders.

4. Methods for Constructing Digital Twin Models of Endangered Species

To build a relatively accurate digital twin model of endangered animals, the frontend needs to collect and preprocess relevant data. This mainly involves the following aspects [5-7]:

Remote sensing technology is used to collect data on animal distribution, habitat, terrain, and climate through satellite and drone remote sensing. Wireless sensor networks, GPS trackers, and bioacoustic monitors are deployed to collect real-time data on animal behavior, physiology, and ecology. This data can be used to study animal activity patterns, reproductive behavior, and interaction relationships. The current common approach is to use camera detection methods and public volunteer participation for data collection. For example, The Zooniverse - Snapshot Serengeti Zooniverse is an online platform that brings together public participants from around the world. Their task is to collaboratively analyze image data from animal monitoring cameras. This project helps to better understand the behavior and habitat needs of endangered animals. The team consists of a multidisciplinary group of six members, including ecologists, biologists, and computer vision experts: Iberia Camera Trap Project Team is shown in Figure 1and Figure 2.

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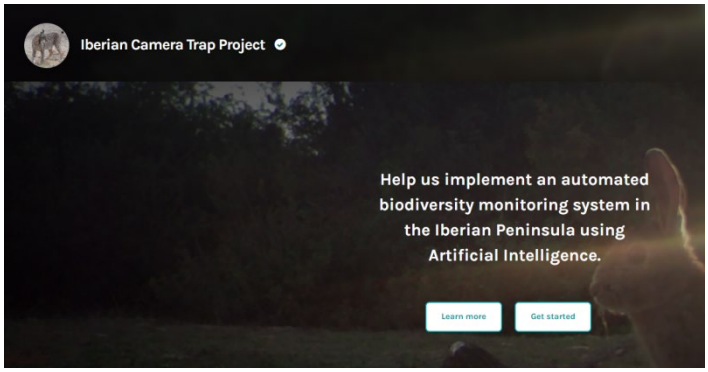

Figure1: Iberian camera trap project

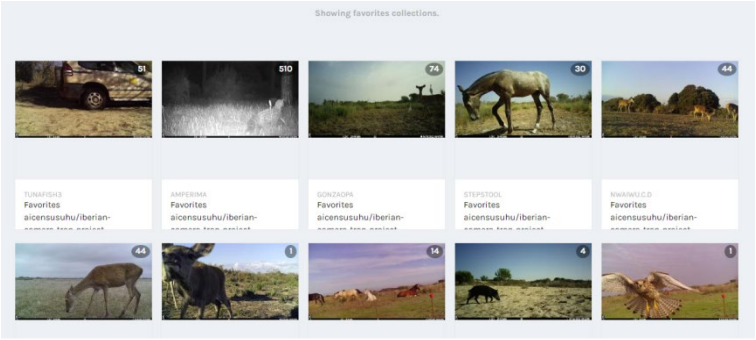

Figure2: Iberian camera trap project bookmark

Biomarker technology: By analyzing animal biomarkers such as genes, metabolites, and hormone levels, information on animal health, disease risk, and environmental adaptability can be obtained. For example, the World Organisation for Animal Health (OIE): A global organization dedicated to the control and protection of animal diseases, monitoring animal health and diseases through biomarkers is shown in Figure 3.

2023 2022 2021 2020 2019 2018 2017 2016 2015 2014 2013

2012 2011 2010 2009 2008 2007

Location	Disease	Date
Kazakhstan	Foot and mouth disease	26 January
North Africa, Middle East and Southeast Asia	Exercise Phoenix against agro-terrorism and agro-crime (WOAH, FAO and INTERPOL)	13 to 28 February
Australia	Exercise FlyWheel on an exotic disease outbreak	March 2023
Nicaragua	Avian Influenza	13 to 17 March
Guyana	High Pathogenicity Avian Influenza	14 to 16 March
Kazakhstan	Sheep pox	19 to 21 April

Figure 3: Latest data on animal health and diseases monitored by biomarkers in 2023

Data preprocessing: Perform preprocessing operations such as quality checks, missing value imputation, data cleaning, and normalization on the collected data to ensure the accuracy and consistency of the data. For example, the World Wildlife Fund (WWF): As an international

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environmental protection organization, WWF has abundant data resources and expertise for endangered animal protection and research. The data undergo quality checks, missing value imputation, data cleaning, and normalization to ensure the accuracy and consistency of the data. One of the ways to fill in missing values is through model-based methods: using existing data to train models, such as regression models, decision trees, or random forests, to predict missing values.

Regardless of data visualization and openness of resources, the sheer volume of content processing alone can cause support for prediction possibilities and decision-making accuracy. Therefore, with the rapid development of artificial intelligence today, robots' deep learning and participation in performing analysis have become key to building endangered animal digital twin models. Robots (such as drones, ground robots, etc.) can collect endangered animals' behavior, ecology, and living environment data and mathematics in remote or harsh environments, process and analyze them in real-time through deep AI, provide real-time updates for the model, and improve the association between physical entities and virtual entities. By using deep AI learning to train classifiers or regression models using known animal distribution and attribute data, the distribution and population status of animals in unknown areas can be predicted. Through clustering analysis, principal component analysis, and other methods, the potential structure and association patterns in animal data can be mined to provide a basis for protection strategies. Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) and other deep learning models can be used to process complex remote sensing images and time series data, improving model prediction accuracy [8].

5. Application and Case Studies of Endangered Animal Digital Twin Models

Endangered animal digital twin models can currently be applied in population dynamics prediction, habitat suitability assessment, and ecosystem service value assessment. Here, we mainly focus on intelligent management technology support for endangered animal protection.

For example, the golden snub-nosed monkey digital twin model was developed by researchers from the Institute of Zoology, Chinese Academy of Sciences, using field data of the golden snub-nosed monkey. The model can detect the monkey's movement and ecological needs in different environments, helping conservationists better develop field protection strategies. Meanwhile, accurately, quickly, and non-invasively identifying and recording wild individuals around the clock has always been a technical challenge faced by zoologists worldwide. It is a critical issue limiting the development of animal behavior and conservation research [9-10].

In response to this cutting-edge issue, Professor Guo Songtao from Northwest University deeply integrated his expertise with experts in the field of computer science to form an animal AI (Artificial Intelligence) research team. The team collaborated with Professor Fang Dingyi, Professor Chen Xiaojiang, and Professor Miao Qiguang from Xi'an University of Electronic Science and Technology to conduct animal AI research. Based on the golden snub-nosed monkey digital twin model, they used image data of the golden snub-nosed monkey to quickly and accurately identify individual monkeys [11-12].

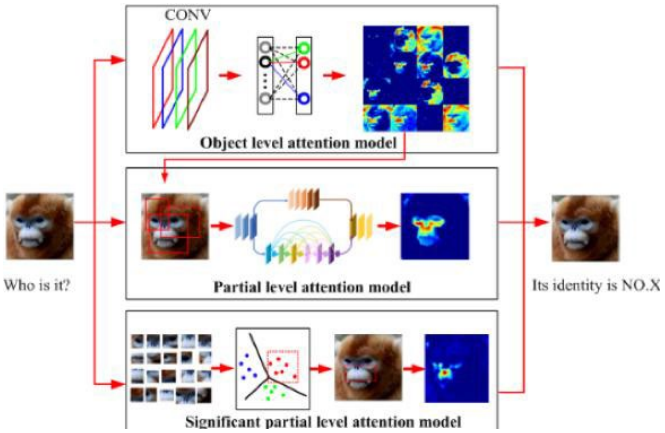

Figure4: Automatic identification of individual primates with deep learning techniques

Leveraging the long-term research results on the species' characteristics by the golden snub-nosed monkey research team, the team proposed a deep neural network model with attention mechanisms using neural network principles. For the first time, they developed an animal individual identification

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system based on Tri-AI technology is shown in Figure 4.

The Tri-AI system overturns traditional methods that rely on individual animal features (such as patterns, colors, scars) or artificially marked features (such as branding, tattoos, dyeing, rings, radio collars, and genetic markers), achieving accurate identification and continuous tracking sampling of wild individuals. More importantly, the system provides the possibility for conducting animal research without an "observer interference effect" under "ideal conditions."

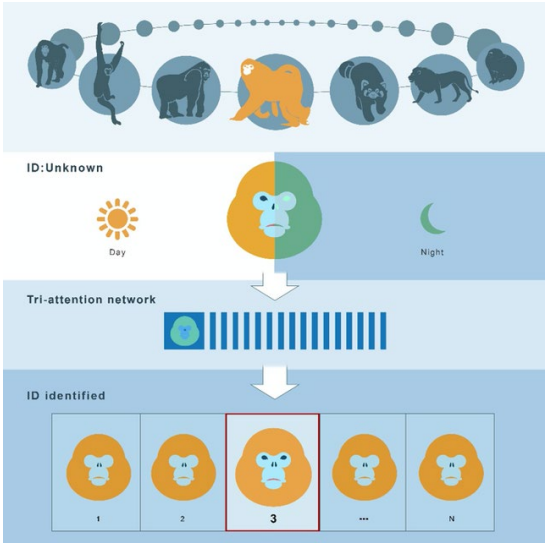

Figure5: Automatic identification of individual primates with deep learning techniques

The Tri-AI system is not only suitable for multiple species but can also analyze nighttime data. At present, the system has undergone applicability verification in 41 representative primate species and four carnivore populations, with an average recognition accuracy of 94.1%. The technology can identify 31 images per second, greatly improving the efficiency of individual data analysis [13]. In the future, it can serve as a core component for big data analysis, providing new technical solutions for zoological research and reliable technical support for the implementation of wildlife protection and intelligent management is shown in Figure 5.

From the above, it can be seen that in practical applications, digital twin models can help scientists gain a deeper understanding of endangered animals' ecosystems, behavioral habits, and population status, providing precise strategies for wildlife protection and further individual research. In future research, the application of digital twin models in other aspects of biodiversity conservation can be further explored to expand the scope of the model. Meanwhile, to better address the challenges in the field of ecological conservation, it is necessary to strengthen the integration of interdisciplinary research and promote knowledge sharing and innovation across different fields.

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