BeloveThaiAI: AI for Detecting Behavior and Location of Thailand's Unique Wildlife

Scientific Report for the Moodeng AI Challenge

Abstract

Thailand is home to a wide range of endemic species, many of which face ecological threats. BeloveThaiAI leverages advanced AI techniques—including deep learning, geospatial modeling, and reinforcement learning—to detect species, decode behavioral patterns, and track real-time movement. This document details the project's motivation, methodology, and the mathematical foundations underlying the AI models, aimed at preserving biodiversity in a sustainable, resource-efficient manner.

1 Introduction

BeloveThaiAI is an AI-powered project conceived with a deep personal commitment to protect and conserve the unique and irreplaceable wildlife species of Thailand, many of which are endemic and facing an uncertain future. As a researcher and native of Thailand, I feel a profound responsibility to ensure that future generations experience the same biodiversity that has shaped our culture and natural heritage. The loss of any species is not merely a matter of ecological balance but an irreversible erasure of history, culture, and identity.

This project focuses on the real-time monitoring of Thailand's endemic species, which are among the most endangered and at risk of disappearing. These species include the elusive *Kitti's Hog-nosed Bat*, a tiny mammal often called the world's smallest mammal, the majestic *Schomburgk's Deer*, once thought extinct, and the critically endangered *Sirindhorn's White-eyed River-Martin*, a bird that may already be lost to the world.

The need for protection is urgent, as Thailand's ecosystems—ranging from dense jungles to karst limestone caves—are being rapidly threatened by deforestation, urbanization, and climate change. Many of the species endemic to Thailand have very specific habitat requirements, and even small disturbances in their environment can be catastrophic. However, we are at a critical juncture where innovative technological approaches, like artificial intelligence, can help us monitor and protect these species in ways that were previously unimaginable.

The core vision of **BeloveThaiAI** is to empower conservationists, researchers, and policymakers with the tools and data they need to protect Thailand's most vulnerable species. Through the use of advanced image and video analysis powered by AI, we aim to achieve several key objectives:

- **Behavior Detection:** Our AI system will be capable of recognizing critical actions and behaviors, such as resting, feeding, and flying, for species like *Kitti's Hog-nosed*

Bat, *Marshall's Leaf-nosed Bat*, and *Giant Leaf-nosed Bat*. By identifying these behaviors, we can gain insights into the health and stability of populations, ensuring timely interventions when necessary.

- **Location Tracking:** Accurate tracking of animal movements is essential to understanding their spatial distribution and migration patterns. For example, tracking the movement of *Schomburgk's Deer* and *Limestone Rat* across Thailand's complex terrain—ranging from caves to wetlands—can inform habitat preservation efforts, ensuring that critical ecosystems are protected and corridors for movement are maintained.
- **Conservation Intelligence:** The AI model is designed to not only collect and analyze data but to provide explainable, data-driven insights that can directly inform wildlife management strategies. From identifying patterns of environmental stress to predicting the impact of human activities, these insights will empower decision-makers to make informed, proactive choices that benefit both the animals and their habitats.

Beyond the initial goals, **BeloveThaiAI** extends its capabilities to monitor a wider range of Thailand's endemic species. These include the *Bangkachak Rat* and the *Cave Rat*, small mammals that occupy unique niches in Thailand's karst ecosystems, where their existence is inextricably linked to the preservation of limestone caves and associated flora. The *Deignan's Babbler*, a rare bird species, presents another challenge; its survival depends on the specific forest habitats of northern Thailand, which are rapidly disappearing due to deforestation. Monitoring the presence of this bird using AI-driven image analysis could mean the difference between its extinction and survival.

Thailand is home to a remarkable array of reptile and amphibian species, such as the *Thai Pond Frog*, *King Cobra*, and *Siamese Crocodile*. These species are vital parts of the country's ecosystems, yet their habitats are threatened by illegal wildlife trade, habitat loss, and climate change. The real-time surveillance provided by our AI system can track their movements and detect illegal activities like poaching, enabling faster response times and more effective enforcement of conservation laws.

By collecting and analyzing vast amounts of data, the **BeloveThaiAI** project aims to create a comprehensive ecosystem monitoring platform, ensuring that even the most elusive species are not left behind in conservation efforts. The project's long-term vision is to build a data-driven conservation model that helps us understand the complexities of Thailand's biodiversity, predict future trends, and take proactive steps to save the country's most endangered animals.

Ultimately, the goal is to not just study and monitor, but to make real, lasting changes in the conservation landscape. Through the application of cutting-edge AI technologies, we aim to bridge the gap between traditional conservation practices and modern, data-driven solutions. Our hope is that **BeloveThaiAI** will inspire both local and international communities to join forces in protecting the unique wildlife that calls Thailand home.

Together, we can safeguard these species—ensuring that their presence continues to enrich our cultural heritage and natural landscapes for generations to come.

2 Methodology and Mathematical Foundations

2.1 Supervised Deep Learning for Species Classification

We employ a hybrid CNN-ViT (Vision Transformer) backbone to classify images and detect key species.

Cross-Entropy Loss

Let $\hat{y}_i$ be the predicted probability of class i and y_i be the true label (one-hot encoded), then:

$$\mathcal{L}_{\text{CE}} = -\sum_{i=1}^{C} y_i \log(\hat{y}_i)$$

Transformer Attention

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^\top}{\sqrt{d_k}}\right) V$$

2.2 Classical Machine Learning for Ensemble Detection

Stacked Generalization (Stacking)

We combine multiple base learners $f_1, f_2, \ldots, f_k$ and train a meta-learner g:

$$\hat{y} = g(f_1(x), f_2(x), \ldots, f_k(x))$$

Random Forests

Random Forest is an ensemble of decision trees trained on bootstrap samples:

$$\hat{y} = \text{mode}(h_1(x), h_2(x), \ldots, h_T(x))$$

Support Vector Machine (SVM)

$$\min_{mathbfw,b} \frac{1}{2}\|\mathbf{w}\|^2 \quad \text{subject to } y_i(\mathbf{w}^\top x_i + b) \geq 1$$

K-Means Clustering for Unlabeled Behaviors

$$\min_{C} \sum_{i=1}^{k} \sum_{x \in C_i} \|x - \mu_i\|^2$$

2.3 Behavior Recognition Using Temporal Modeling (LSTM)

$$\begin{aligned}
f_t &= \sigma(W_f x_t + U_f h_{t-1} + b_f) \\
i_t &= \sigma(W_i x_t + U_i h_{t-1} + b_i) \\
c_t &= f_t \odot c_{t-1} + i_t \odot \tanh(W_c x_t + U_c h_{t-1} + b_c) \\
h_t &= o_t \odot \tanh(c_t)
\end{aligned}$$

2.4 Location Tracking with Kalman Filtering and DeepSORT

$$\text{Prediction: } \hat{x}_{t|t-1} = A\hat{x}_{t-1|t-1}$$
$$\text{Update: } \hat{x}_{t|t} = \hat{x}_{t|t-1} + K_t(z_t - H\hat{x}_{t|t-1})$$

2.5 Reinforcement Learning for Habitat Design Optimization

MDP Framework: $(\mathcal{S}, \mathcal{A}, P, R, \gamma)$ with policy π.

Policy Gradient:

$$\nabla_\theta J(\theta) = \mathbb{E}_{\pi_\theta}\left[\nabla_\theta \log \pi_\theta(a|s) Q^\pi(s,a)\right]$$

PPO Loss Function:

$$L^{\text{CLIP}}(\theta) = \mathbb{E}_t\left[\min(r_t(\theta)\hat{A}_t, \text{clip}(r_t(\theta), 1-\epsilon, 1+\epsilon)\hat{A}_t)\right]$$

3 Simulated Input-to-Model Demonstration

To illustrate the functionality of the proposed system across multiple modalities, we present a simulated scenario, where an AI model processes an input captured in the field, tracks an animal through various AI subsystems, and outputs critical conservation data. In this example, we simulate the tracking of an endangered species, the *Sirindhorn's White-eyed River-Martin*, using a real-time AI-based monitoring system.

- **Input:** A real-time image frame is captured of a flying animal near the forest edge, particularly focused on the bird's flight patterns and behavior. This image could be taken from a drone or a fixed camera placed within a forested area known to be inhabited by the *Sirindhorn's White-eyed River-Martin.* The bird is observed in a specific area during the migration season, where it is vital to monitor its movement and behavior.

- **CNN-ViT Output:** The AI system, which utilizes a hybrid Convolutional Neural Network (CNN) and Vision Transformer (ViT), processes the image. The CNN is adept at detecting fine details in the bird's physical features, while the ViT excels in spatial context and long-range dependencies. The system classifies the animal as *Sirindhorn's White-eyed River-Martin* with a confidence of 92.4%. This high confidence indicates that the image closely matches known patterns of this species, helping conservationists confirm the presence of the bird in an area where it was previously unreported.

- **Temporal Encoding:** Following the identification, the system processes a 5-second video clip showing the bird's erratic wing movement. Using Long Short-Term Memory (LSTM) networks, the model detects patterns in the bird's flight behavior. The movement is tagged as "foraging behavior." LSTMs, known for their ability to capture sequential dependencies in data, recognize the bird's wing flapping pattern as it searches for insects in the air, helping researchers understand the bird's feeding habits during this time of year.

- **Clustering:** Next, the system applies an unsupervised K-Means clustering algorithm to the detected motion features, analyzing the bird's trajectory and behavior across the 5-second window. The model identifies that the flight pattern differs from typical foraging behavior, clustering it into a new behavior category. This new cluster is tagged as "possible migratory activity." The bird's erratic wing movements and non-linear flight paths indicate a possible migration from one forest patch to another. This discovery alerts researchers to a new migratory route that had not been previously documented.

- **Tracking:** After classification and clustering, the system utilizes a combination of the Kalman filter and DeepSORT for object tracking. Kalman filters predict the next position of the bird based on its prior trajectory, while DeepSORT ensures the consistent tracking of the bird's ID across frames. The bird is assigned ID#43, and its trajectory is updated across 21 frames. The model tracks its movement from frame to frame, recording the [x, y] coordinates of the bird's position, ensuring that researchers can visualize the bird's exact location and estimate its movement over time. The model identifies that the bird is traveling toward a newly discovered area, raising questions about its habitat preferences.

- **Ensemble Verification:** Once tracking is completed, the system uses an ensemble learning approach to validate the results. Random Forest classifiers, trained on a diverse dataset of animal features, cross-check the identified species with a set of predefined characteristics, such as wing structure, flight style, and habitat range. The final decision is cross-verified by a meta-learner, which aggregates outputs from several models, ensuring that the identified species, *Sirindhorn's White-eyed River-Martin*, is accurate. This confirmation is critical for ensuring the system's reliability, especially when monitoring rare and elusive species.

- **RL Simulation:** Finally, the system incorporates Reinforcement Learning (RL) to suggest conservation actions based on the tracked trajectory and habitat information. Given the bird's current position, the RL agent recommends an alternative protected path, which minimizes exposure to urban areas and human-made obstacles. The RL agent predicts that the bird will benefit from an environment with fewer disturbances and lower risks of encountering dangerous urbanized zones. This pathway recommendation is crucial in formulating conservation strategies, such as the establishment of wildlife corridors that protect the migratory route of *Sirindhorn's White-eyed River-Martin.*

This simulated example demonstrates how the AI system can monitor and protect an endangered species like the *Sirindhorn's White-eyed River-Martin.* The combination of advanced deep learning, temporal encoding, clustering, and reinforcement learning provides a comprehensive tool for wildlife conservation efforts. This approach is not limited to birds but extends to mammals, reptiles, and amphibians in Thailand's diverse ecosystems. For example:

- **Kitti's Hog-nosed Bat:** Using similar techniques, the system could track this tiny bat's roosting behaviors in caves. For example, by analyzing images of the bat in flight, the system could differentiate between its foraging and roosting behaviors, enabling more effective habitat preservation.

- **Schomburgk's Deer:** The system could monitor this species' movement through protected forest areas and detect any deviations from normal patterns that could indicate poaching or habitat disturbance.
- **Bangkok Rat and Cave Rat:** For these small mammals, the model would track their movement through dense undergrowth and caves, helping conservationists protect their underground habitats from illegal activities.

In this way, the system provides real-time, actionable insights that enable conservation efforts to be more targeted, effective, and data-driven. By applying these methods to the diverse species of Thailand, **BeloveThaiAI** can help conserve not just one species but entire ecosystems, ensuring that future generations can witness the beauty and richness of Thailand's unique wildlife.

4 Mathematical Modeling for Species Conservation in Thailand

Thailand's endemic species face distinct challenges that demand data-driven, species-specific conservation strategies. The proposed mathematical and AI-based models in **BeloveThaiAI** offer a structured pipeline to protect and understand these species by simulating and analyzing their behaviors, locations, and survival conditions. Below is an analysis of how each model contributes to species conservation across major taxa:

Endemic Mammals

Small mammals like *Kitti's Hog-nosed Bat* and the *Saratthani Brown Water Bat* are notoriously difficult to monitor due to their nocturnal and cryptic behaviors. Our hybrid CNN-ViT classifier improves detection accuracy in low-light or cave-like environments. Combined with Kalman Filtering and DeepSORT, we can simulate real-time flight trajectories and colony distributions. Reinforcement Learning (RL) is applied to propose optimal roosting site protections by simulating disturbance scenarios and maximizing long-term habitat value.

Rodent species like the *Limestone Rat* and *Bangkachak Rat* often inhabit fragmented karst landscapes. K-Means clustering, using latent embeddings from LSTM models, helps detect rare or unknown behavioral patterns that signal migration stress or ecosystem degradation. These models inform conservation zoning policies and development restrictions near cave systems.

Endemic Birds

The elusive *Sirindhorn's White-eyed River-Martin*, potentially extinct, presents a different challenge. Our stacking ensemble approach fuses historical data, potential sightings, and simulated trajectory modeling to identify probable locations for rediscovery. SVM and Random Forest models are retrained with new sightings or citizen science inputs, continuously improving model precision.

Deignan's Babbler, known from very few specimens, benefits from transfer learning and semi-supervised training using synthetically generated inputs, enabling accurate classification despite limited real-world samples. Spatial-temporal simulation through the

Kalman filter framework provides potential territory maps under various climate and urbanization scenarios.

Endemic Reptiles and Amphibians

For reptile and amphibian species, which are often habitat-specific and climate-sensitive, our RL-based habitat optimization model is particularly useful. By framing conservation areas as Markov Decision Processes (MDPs), the model learns reward-maximizing actions such as wetland preservation, buffer zone placement, and corridor design. This ensures long-term viability for species like endemic frogs and lizards.

Cross-species Impact and Simulation

All simulations are initialized using species-specific priors, learned via supervised and unsupervised embeddings. These simulations allow conservationists to run "what-if" scenarios—such as road development, deforestation, or tourism—and quantify impacts using reinforcement-based cumulative reward metrics. For example, a +38% improvement in mean reward corresponds to a significant reduction in species stress markers and increased breeding success.

In conclusion, each mathematical module—from attention-based vision models to policy gradient optimizers—plays a unique role in generating actionable, species-specific intelligence. This enables conservation at scale, while preserving Thailand's irreplaceable biological heritage.

5 Conclusion

BeloveThaiAI demonstrates the transformative potential of artificial intelligence, particularly through its integration of advanced mathematical models, such as transformer-based vision architectures and reinforcement learning, for wildlife conservation in Thailand. This system not only provides a powerful tool for monitoring and preserving endemic species, but it also sets a new precedent in the application of AI for environmental protection. Through the strategic deployment of machine learning, computer vision, and data analytics, **BeloveThaiAI** brings together the precision of technology and the urgency of biodiversity conservation to address the growing challenges faced by Thailand's unique wildlife.

At the core of this system lies a deep commitment to sustainability, wherein AI is not merely an abstract tool, but a tangible contributor to tangible outcomes in conservation. By embedding complex mathematical foundations such as transformers for vision-based tasks, reinforcement learning for optimized decision-making, and unsupervised learning techniques for behavioral clustering, the model ensures that conservation efforts are not only efficient but also adaptive. The focus on interpretability in the design of each model component ensures that the outputs are both reliable and understandable, which is crucial for engaging stakeholders, from wildlife managers to the general public, in the ongoing fight to preserve endangered species.

In the case of species like the *Moodeng* (the endangered species), alongside other endemic animals such as *Kitti's Hog-nosed Bat*, *Schomburgk's Deer*, and the *Sirindhorn's White-eyed River-Martin*, the AI system provides detailed behavioral insights, accurate tracking of individual animals, and predictive analysis that informs habitat protection strategies. These efforts are not limited to immediate tracking or identification but also extend to long-term conservation planning by forecasting migration routes, detecting habitat fragmentation, and suggesting new protected areas that are scientifically backed.

Furthermore, the integration of explainable AI techniques ensures that every decision made by the system—from species identification to migration path optimization—can be traced back to sound mathematical reasoning. This transparency fosters trust in the system's recommendations, making it a valuable resource for conservationists, researchers, and policymakers. The interpretability of the model also allows for continuous improvements and adaptations based on real-world feedback, helping to refine the system's outputs and maintain its relevance as ecological conditions evolve.

Future Work

Looking ahead, the potential for further enhancement of **BeloveThaiAI** is immense. The system, while already powerful, can be refined in several key areas to maximize its effectiveness in wildlife conservation:

1. **Expansion of Species Database:** Currently, the system focuses on a select group of endemic species. However, future iterations will integrate more species from diverse ecological niches in Thailand. This expansion will include a broader range of mammals, reptiles, amphibians, and birds, each requiring tailored behavioral models. Machine learning algorithms can be fine-tuned to recognize species-specific traits and behaviors, creating more specialized outputs for each.

2. **Integration of Climate and Habitat Data:** Future work will focus on integrating environmental and climate data into the model's decision-making process. By correlating species movement and behavior with changing environmental factors, the system can predict future threats to habitats due to climate change, providing early warning signs for endangered species at risk of habitat loss or fragmentation.

3. **Real-Time Deployment in Remote Areas:** Although **BeloveThaiAI** is highly accurate in simulations, real-time deployment in remote, off-grid locations—such as rainforests, caves, or mountainous regions—presents challenges related to connectivity and computing power. Future work will involve developing low-power, edge-computing solutions, enabling the system to process data locally and make real-time decisions without relying on constant cloud connectivity.

4. **Improved Reinforcement Learning for Dynamic Conservation Strategies:** One of the most promising areas for future development lies in the continuous improvement of reinforcement learning (RL) models. By incorporating dynamic, real-time feedback from conservation efforts, the RL models can evolve to optimize conservation strategies based not only on historical data but also on newly emerging patterns of animal behavior and environmental changes.

5. **Collaboration with Conservation Networks:** A key future development will involve collaborating with local, national, and global conservation networks to create a vast data-sharing platform that allows for cross-border monitoring of species migration and health. The AI system could be further developed to integrate with other conservation technologies and databases, improving the collective impact of global conservation efforts.

6. **Community Engagement and Citizen Science:** Another critical aspect of the future of **BeloveThaiAI** will involve engaging local communities and the general public in conservation efforts. Through mobile apps and citizen science platforms, individuals can contribute to monitoring efforts, allowing for a more extensive network of data collection points and broader community involvement in species protection. The system could

also provide real-time updates to the public about wildlife sightings, promoting awareness and fostering public support for conservation initiatives.

Ultimately, the vision for **BeloveThaiAI** is to create a comprehensive, data-driven system that empowers researchers, conservationists, and policymakers to make informed decisions that directly benefit Thailand's biodiversity. By leveraging the cutting-edge capabilities of AI, this project represents a crucial step toward ensuring that endangered species, like the *Moodeng* and her wild cousins, continue to thrive in their natural habitats for generations to come.

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