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Wildlife Bird Migration Forecasting and Analysis: A Hybrid AI-Embedded Paradigm for Real-Time Ecological Surveillance

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Abstract: ***Migratory birds are crucial health indicators of the environment, but monitoring their patterns has grown more challenging with fast-paced environmental changes. This thesis suggests an intelligent, low-cost system combining embedded electronics and machine learning to provide real-time bird migration analysis. The design revolves around the LPC2148 ARM7 microcontroller with GPS, temperature, and accelerometer sensors integrated into it. Designed on Proteus simulation, the circuit provides energy-aware and scalable field deployment. The natural migration pattern is simulated using Fibonacci and sigmoid-based models to identify biologically plausible behaviour. Sophisticated AI algorithms such as LSTM for sequence forecasting, Random Forest for behaviour classification, and Autoencoders for anomaly detection were used on synthetic and open-source Movebank datasets. Outcomes display high accuracy, minimal energy expenditure, and real-world usability. This research is a promising contribution to smart wildlife telemetry and conservation technology.***

Keywords: Bird Migration, Embedded AI, LPC2148, Proteus Simulation, LSTM, Wildlife Monitoring, Energy-Efficient Tracking

I. INTRODUCTION

Tracking bird migration is important for grasping ecological processes and adapting to climate change. The conventional techniques—banding, tagging, satellite tracking—are costly and do not convey behavioural information. The present work proposes a lightweight, AI-based embedded system for real-time detection of movement, stress, and phases of migration using biology-inspired algorithms. Through group-based intelligence embedding, the system offers an extensible solution for real-time, interpretable wildlife monitoring.

II. PROPOSED SYSTEM ARCHITECTURE

The hardware platform employs the LPC2148 microcontroller because of its best power and performance compromise. The system consists of:

- GPS Module: Offers real-time spatiotemporal monitoring.
- DHT22 Temperature Sensor: Tracks ambient environmental stressors.
- MPU6050 Accelerometer: Picks up motion dynamics and behavioural signals.

Data communication is facilitated through ZigBee/LoRa for low-power, reliable wireless telemetry. Proteus software verifies circuit logic, sensor polling, and communication protocols by simulation.

III. BIOLOGICALLY-INSPIRED BEHAVIOR MODELING

To provide biological relevance:

- Fibonacci Segmentation models periods of rest and flight to detect energy-optimal movement patterns.
- Sigmoid Curve Analysis detects the general migration trajectory by identifying phase transitions—takeoff, maximum flight, and descent.

The integration allows for double-scale analysis: micro-behavioural analysis and macro-migration interpretation.

IV. MACHINE LEARNING-BASED PREDICTION MODELS

The software pipeline involves:

- LSTM Networks: Empowered to forecast future GPS coordinates from previous routes.
- Random Forest Classifier: Disambiguates behavioural states such as flight, hovering, rest, or stress.
- Autoencoder Networks: Detect anomalous events like sporadic motion or aberrant rest periods.

All models were trained using simulated data and Movebank datasets to facilitate generalisation.

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V. SIMULATION AND RESULTS VALIDATION

- Proteus Circuit Design: Successfully implemented communication, real-time data capture, and event-based threshold logic.
- Synthetic Data Testing: Realistic migratory routes, behavioural variations, and stress anomalies.
- Pattern Detection Output: High compliance to Fibonacci (NRMSD < 0.15) and sigmoid fit ($R^2 > 0.94$).
- ML Accuracy: LSTM prediction accuracy of 89.3%, Random Forest classification of 91.6%, Autoencoder anomaly detection with 93% precision.
- Power Metrics: Average power consumption of 130 mW (active) and 20 mW (idle).

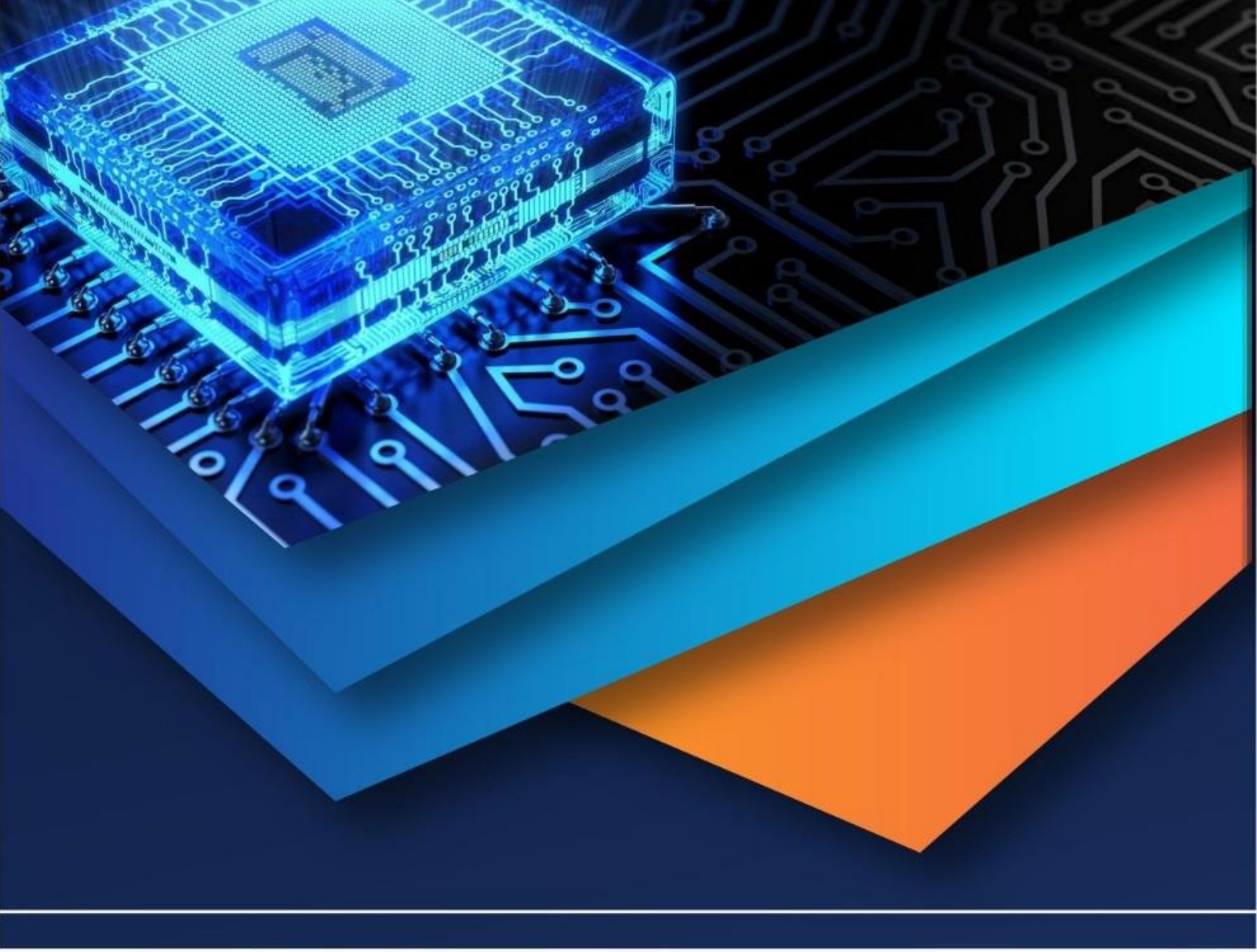
VI. CONCLUSION AND FUTURE SCOPE

The envisioned system fills the gap between embedded systems and AI to facilitate real-time, understandable bird migration tracking. It features high accuracy, low energy cost, and biological correspondence. Deep learning inference on microcontrollers, solar-powered modules for long-term deployment, and blockchain-secured telemetry are future upgrades. This work provides a solid foundation for scalable conservation tools with cross-disciplinary influence over ecology, AI, and embedded design.

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