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An ESP32-CAM Embedded Data Infrastructure for Database-Driven Emotion-Based Student Readiness Assessment

Edward Junior[1], Daniel Guzmán[1], Miguel Postigo[1], Israel Torné[1]
1 PPGEEL- Postgraduate Program in Electrical Engineering, School of Technology, State University of Amazonas (UEA), Manaus 69050-020, Brazil

INTRODUCTION & AIM

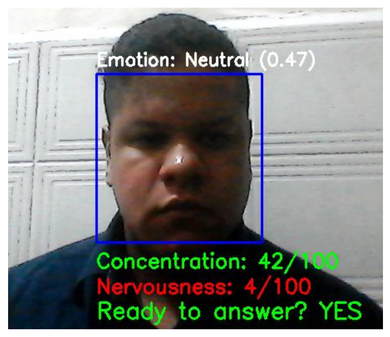
This work addresses the growing need for intelligent and scalable systems capable of monitoring students' emotional states during academic activities. Emotional indicators such as concentration and nervousness play a crucial role in learning performance and cognitive engagement.
Traditional approaches often rely on centralized systems with limited real-time data acquisition capabilities. In contrast, embedded systems offer a low-cost and scalable alternative for distributed data collection.
The main objective of this work is to develop an embedded data infrastructure using ESP32-CAM devices capable of capturing, transmitting, and storing facial images for emotion-based student readiness assessment.
Additionally, this work aims to demonstrate how integrating embedded systems with centralized databases and machine learning models can support data-driven educational environments. By leveraging ESP32-CAM modules as distributed sensing units and combining them with centralized database systems, it is possible to explore a novel approach in which embedded devices are not only responsible for data acquisition but also play a strategic role in building large-scale datasets.

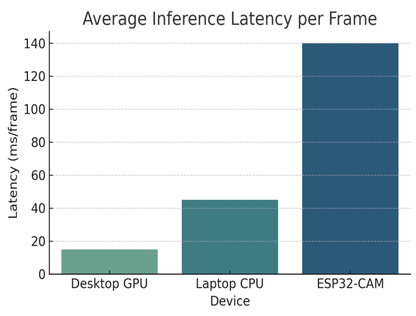
METHOD

The proposed system is based on a **distributed embedded architecture**, composed of multiple ESP32-CAM modules acting as sensing nodes.
* Each ESP32-CAM captures facial images during student activities.
* Lightweight preprocessing is applied (resizing, noise reduction)
Images are transmitted via Wi-Fi to a centralized database.
The database organizes and stores images for further processing
A **Convolutional Neural Network (CNN)** trained on the FER2013 dataset is used to classify emotions into categories such as:
* Happiness
* Sadness
* Anger
* Neutral
* Surprise
These emotional outputs are then mapped into **student readiness indicators**, including:
* Concentration level
* Nervousness level
This architecture separates **data acquisition (embedded layer)** from **data processing (centralized AI layer)**, improving scalability and flexibility.

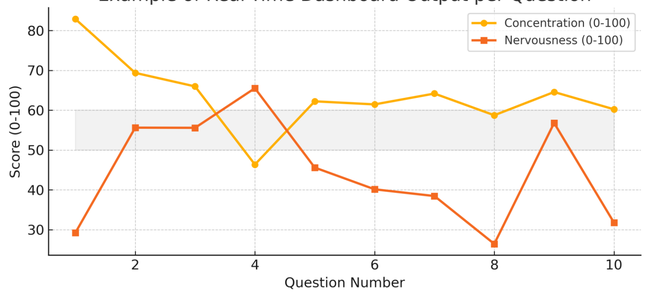
RESULTS & DISCUSSION

The experimental evaluation demonstrates that the proposed system is capable of:
* Providing **stable image acquisition** using ESP32-CAM devices
* Maintaining **reliable wireless transmission** in classroom-like environments
* Supporting **continuous and long-term data collection**
The centralized database enables:
* Efficient storage and indexing of facial images
* Historical tracking of student emotional patterns
* Aggregation of data for large-scale analysis
The CNN model successfully classifies facial emotions, allowing the system to estimate concentration and nervousness levels with practical relevance.
Additionally, the modular architecture allows future improvements, such as:
* Integration of more advanced deep learning models
* Real-time feedback systems
* Expansion to multimodal data (e.g., audio, physiological signals)





Example of Real-Time Dashboard Output per Question



CONCLUSIONS

This work presents a **scalable and low-cost embedded infrastructure** for emotion-based student readiness assessment.
The integration of ESP32-CAM devices with a centralized database and neural network models demonstrates that:
Embedded systems can act as efficient **distributed data acquisition units**
Centralized processing enables **flexible and updatable AI models**
The proposed architecture supports **data-driven educational applications**
Overall, the system bridges the gap between embedded hardware and intelligent data analysis, contributing to the development of **emotion-aware educational technologies**.

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