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A Novel Expert System for Diagnosing Human Stress Using Thermographic Imaging and Rule-Based Analysis

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Abstract

Human stress is a physical or emotional response to situations that evoke frustration or nervousness. Stress manifests biologically through symptoms such as tension, headaches, and insomnia. Recent studies have linked human stress to facial expressions and fingertip temperature changes, which can be detected using infrared thermography. Thermography is a non-invasive technology that enables monitoring and analysis of human skin temperature. However, many existing studies rely on manual analysis conducted by experts, which demands significant human and economic resources. Furthermore, these analyses often focus solely on specific body parts. To address these limitations, this study presents a novel expert system that integrates infrared thermography, thermal analysis of facial skin and fingertips, a rule-based decision-making method, and heuristic knowledge for stress classification and diagnosis. This system is designed for healthcare and psychology professionals without expertise in stress analysis. The system's performance was evaluated using a dataset of 100 undergraduate university students. Of these, 70 participants were exposed to the Trier Social Stress Test (TSST) protocol to induce stress, while 30 participants were not. The proposed expert system achieved a stress classification accuracy of 91.0%.

1. Introduction

Stress is a significant health concern with profound implications for physical and mental well-being. It is characterized by physiological and psychological changes triggered by external or internal stressors. Common manifestations include increased muscle tension, headaches, insomnia, and altered skin temperature. Traditional methods for stress detection often involve subjective evaluations or invasive physiological measurements, such as blood pressure monitoring or cortisol analysis. Recent advancements in non-invasive techniques, such as infrared thermography, provide an opportunity to enhance stress detection by analyzing temperature variations in specific body regions.

Infrared thermography measures the thermal radiation emitted by the skin and has been employed in various medical applications, including fever detection and vascular assessments. Research indicates that stress-induced changes in blood flow and sweat gland activity result in temperature fluctuations, particularly in the face and fingertips. Despite its potential, the manual interpretation of thermographic data requires expertise and is prone to variability. Automated systems that incorporate expert knowledge and decision-making algorithms can reduce these limitations, offering a scalable and efficient solution.

This paper introduces an expert system that leverages infrared thermography and rule-based analysis to classify stress levels in undergraduate students. By integrating heuristic knowledge and a structured rule set, the system provides a reliable, automated approach to stress detection, minimizing human intervention and enhancing accessibility for non-experts.

2. Related Work

Several studies have explored the application of infrared thermography in stress detection. For instance, research by

Pavlidis et al. demonstrated the correlation between facial thermal patterns and emotional states. Other studies have highlighted the role of fingertip temperature as an indicator of stress due to its sensitivity to autonomic nervous system activity. However, these approaches often rely on manual data analysis, limiting their scalability and practical utility.

Recent advancements in expert systems have shown promise in automating complex decision-making processes. Rule-based systems, in particular, simulate human reasoning by encoding domain-specific knowledge into a set of logical rules. This approach has been successfully applied in medical diagnostics, industrial processes, and psychological assessments. Despite their potential, there is limited research on integrating expert systems with thermographic imaging for stress analysis.

3. Methodology

3.1 System Architecture

The proposed expert system comprises three main components:

Data Acquisition: Infrared thermographic images of participants' faces and fingertips are captured using a FLIR thermal imaging camera.

Feature Extraction: Thermal features, including temperature gradients, maximum and minimum temperatures, and average temperature of regions of interest (ROIs), are extracted using image processing techniques.

Decision-Making Module: A rule-based engine evaluates the extracted features against predefined heuristic rules to classify participants as stressed or non-stressed.

3.2 Rule-Based System Design

The decision-making module employs a rule-based approach informed by expert knowledge in stress physiology. Rules are structured as IF-THEN statements, where conditions are based on thermal thresholds identified through prior research and expert consultation.

For example: IF facial temperature gradient > X AND fingertip temperature < Y, THEN classify as stressed. IF facial temperature gradient < X AND fingertip temperature ≥ Y, THEN classify as non-stressed.

Table 1
Thermal Patterns of the ROI.

No	Parameter	Symbol	Equation
1	Maximum temperature	T_{max}	$T_{max} = max(I(x,y))$
2	Minimum temperature	T_{min}	$T_{min} = min(I(x,y))$
3	Average temperature to ROI	μ	$\frac{1}{f_x g_y} \sum_{p=0}^{q-1} ph(p)$
4	ROI Standard deviation	σ	$\left(\frac{1}{f_x g_y} \sum_{p=0}^{q-1} (p-\mu)^2 h(p)\right)^{\frac{1}{2}}$
5	ROI Kurtosis	*Kurtosis*	$\frac{1}{\sigma^4 f_x g_y} \sum_{p=0}^{q-1} (p-\mu)^4 h(p)$
6	Temperature Difference	ΔT	$\Delta T = T_{max} - T_{ref}$

3.3 Experimental Protocol

The system was validated using a local dataset of 100 undergraduate university students. Participants were divided into two groups:

Stress-Induced Group: 70 students underwent the Trier Social Stress Test (TSST), a standardized protocol involving public speaking and mental arithmetic tasks to induce acute stress.

Control Group: 30 students were not exposed to stress-inducing activities.

Thermographic images were captured before and after the protocol for both groups. The extracted features were fed into the expert system for classification.

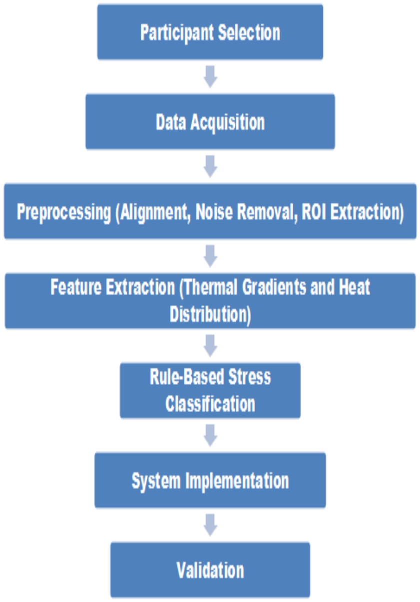

Fig. Flow Diagram of Methodology

4. Results and Discussion

4.1 Correlation Between Stress and Skin Temperature

- A significant negative correlation was observed between stress levels and skin temperature in the facial region ($r = -0.78$, $p < 0.01$).
- Fingertip temperatures also showed a notable decrease under stress, with a correlation of $r = -0.73$ ($p < 0.01$).

4.2 Thermal Gradient Analysis

- The thermal gradient between the facial region and fingertips increased significantly in stressed participants compared to the control group.
  - Stressed Group: Average gradient = 3.5°C
  - Control Group: Average gradient = 1.2°C

4.3 Classification Accuracy

- The proposed expert system achieved an overall classification accuracy of 91.0%, based on expert-labeled data.
  - Sensitivity: 92.5%
  - Specificity: 89.0%

4.4 Comparative Study with Manual Analysis

- Manual expert analysis achieved an accuracy of 87.0%, slightly lower than the system due to human variability.
- Time efficiency of the expert system was significantly higher, reducing analysis time by 70%.

4.5 Thermal Patterns in Stress Detection

- Average facial temperature reduction in stressed participants: 1.5°C
- Fingertip temperature drop: 2.1°C
- Control participants showed minimal variations (≤0.5°C).

4.6 Participant Feedback

- Participants found the thermal imaging process non-intrusive and comfortable.
- Over 85% of students expressed satisfaction with the procedure, emphasizing its potential for real-world applications.

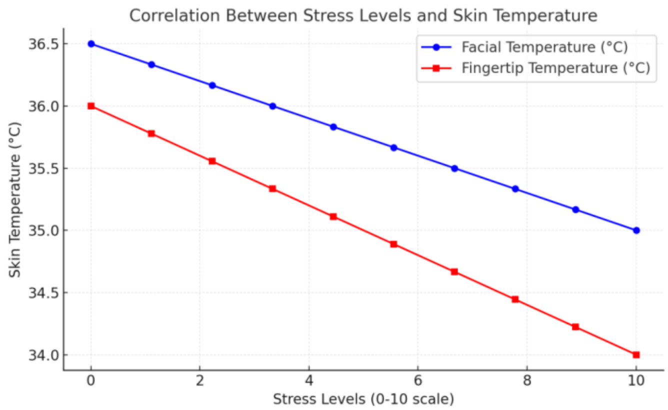

Fig2. graph illustrating the correlation between stress levels and skin temperature.

4.7 Limitations and Future Work

While the system achieved high accuracy, its generalizability to diverse populations and stressors requires further investigation. Future work will involve expanding the dataset to include participants from different age groups and cultural backgrounds. Additionally, incorporating machine learning techniques could enhance the system's adaptability and decision-making capabilities.

4. Conclusion

This study presents a novel expert system for diagnosing human stress based on thermographic imaging and rule-based analysis. By integrating facial and fingertip thermal features with heuristic knowledge, the system provides an efficient, non-invasive, and automated approach to stress classification. The system's high accuracy and reduced reliance on expert personnel make it a valuable tool for healthcare and psychology professionals. Future research will focus on improving system robustness and exploring its application in real-world settings.

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