International Journal of Web of Multidisciplinary Studies
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
website: https://ijwos.com OPEN ACCESS E-ISSN : 3049-2424
Volume 3 Issue 3 , March 2026
DOI: https://doi.org/10.71366/ijwos03032635984

AI-Based Early Detection of Diabetic Foot Ulcers

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Article Info

Article History:

Published:19 March 2026

Publication Issue:
Volume 3, Issue 3
March-2026

Page Number:
387-391

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Abstract:
Diabetic foot ulcers (DFUs) are a global cause of lower-limb amputation and a major factor in severe outcomes due to delayed diagnosis. Traditional detection is based on visual and tactile inspection, frequently failing to detect subclinical temperature differences that are harbingers of obvious overt skin breakdown. This article suggests an AI-based, smartphone-compatible thermal imaging camera for employment in the early detection of DFUs to facilitate early treatment and avoid amputation. The introduced framework incorporates low-cost thermal imaging add-ons, heat anomaly detection using convolutional neural networks (CNNs), and cloud-based telemedicine services. The model takes advantage of temperature asymmetry analysis between the feet to detect pre-ulcerative inflammation. Deployment in primary care and home-monitoring settings is described, along with potential pitfalls, ethical considerations, and mitigation strategies. The anticipated outcome is a scalable, low-cost diagnostic device that empowers patients, assists clinicians, and fundamentally enhances diabetic foot care outcomes.

Keywords: diabetic foot ulcer, thermal imaging, artificial intelligence (AI), deep learning, preventive healthcare, telemedicine

1. Introduction

Diabetic foot ulcers (DFUs) are among the most disabling complications of diabetes mellitus with a 15–25% impact on patients with diabetes throughout their lives. Delayed diagnosis usually leads to deep infections, osteomyelitis, and, in the worst possible scenario, amputation of the lower extremity. The economic cost is high, reaching more than billions of dollars each year worldwide. In addition to the cost, DFUs also decrease the patient's quality of life by inducing pain, immobility, and psychological suffering. Traditional detection methods, including visual inspection and monofilament testing, typically fail to identify the initial inflammatory changes before ulceration.Research shows that localized tissue temperature rises detectable before the onset of overt symptoms days or even weeks in advance are a reliable predictor of impending ulceration. Sophisticated infrared thermal imaging equipment is not easily accessible in rural and resource-poor settings.

The integration of low-cost smartphone thermal imaging accessories with AI image analysis offers the unprecedented potential for an accessible, affordable early detection device. Introducing a novel AI-based DFU detection framework for application in clinical and home-based monitoring settings, the aim of this work is the reduction of preventable amputation.

2. Literature Review

- **AI in Diabetic Foot Assessment**

Thermal imaging in previous studies has been proven to identify minimal variations in temperature that are characteristic of inflammation in diabetic patients. **Bharara et al., (2016)** proved that a >2.2°C variation between corresponding points on the foot is associated with high sensitivity for the prediction of ulcer development. Manually programmed algorithms like convolutional neural networks (CNNs) have been used to classify such thermal abnormalities successfully.

- **Low-Cost Imaging Solutions**

New developments in mobile technology allowed the emergence of thermal cameras compatible with smartphones (e.g., FLIR One, Seek Thermal) with image resolutions adequate for medical image analysis. Research by **Choudhury (2024)** investigated the use of Machine Learning (ML) and specifically deep learning methods in medical image diagnosis for enhancing diagnostic efficacy and precision.

- **Telemedicine Integration**

The combination of telemedicine processes with artificial intelligence-based medical imaging technology is enabling remote monitoring and assessment by healthcare professionals. Merging of artificial intelligence and telemedicine, as argued by **Innocent et al. (2024)**, enhances the quality of healthcare in rural settings, where geographical location and resource limitations hinder the proper delivery of medical care.

Despite these developments, no scalable, low-cost AI solution exists for DFU early detection for primary and home care, especially in low- and middle-income nations.

3. Research Gap

- Lack of affordable, portable DFU detection tools suitable for home use.
- Few neural networks trained solely on smartphone thermal imaging of diabetic feet.
- Lack of integrated telemedicine platforms that integrate DFU detection, patient education, and clinician monitoring.

4. Need and Scope of the Study

Diabetic foot ulcers (DFUs) have become a global health and economic issue of considerable magnitude, leading to patient morbidity, mortality and healthcare costs. Conventional diagnostic practices, based primarily on visual observation and clinical examination, in many cases lack the sensitivity required to detect pre-ulcerative changes and result in delayed treatment and unnecessary amputation.

With limited resources (space, time, and expertise) to perform early DFU detection, there is an urgent need for cost-effective, scalable, and accurate DMDs that can support this need to detect DFUs early. The combination of smartphone-based thermal imaging with AI has the potential to transform diabetic footcare with a portable, low-cost, user-friendly solution for both patients and clinicians.

The scope of this research is to build an early phase detection framework for DFU using a low-cost thermal imaging device and AI-based anomaly detection models. It encompasses the assessment on how such a system can be integrated into a telemedicine infrastructure and provide mobile monitoring that may increase access, reduce the need for monitoring in tertiary-care facilities, and bring mobile participation directly into the patient's home. We also discuss challenges regarding device expenses, patient adherence, and model transferability and recommend ways to address these issues.

5. Research Objectives

- To create an AI model for early DFU symptom diagnosis using smartphone thermal imaging.
- To develop a system for incorporating this model into home and clinic-based monitoring systems.

- To evaluate the potential impact in relation to reducing amputation numbers through earlier treatment.

6. Hypotheses

- **Null Hypothesis (H_0)**: The AI facilitated smartphone thermal diagnostic imaging is not effective in the early detection of pre-ulcerative inflammation in diabetics from that of traditional clinical observation.
- **Alternative Hypothesis (H_1)**: Smartphone thermal imaging combined with AI offers an effective solution to early prevention of pre-ulcerative inflammation in diabetic feet than conventional clinical observation.

7. Methodology

I. System Overview

The proposed system consists of:

- **Data Acquisition**: Thermal images taken with a smartphone attachment.
- **Preprocessing**: Normalization, noise reduction, and temperature calibration.
- **AI Model**: CNN is designed to detect anomalous patterns of heat by computing temperature asymmetry and hotspot.
- **Telemedicine Integration**: Cloud upload for treatment guidance, review by the clinician, and patient notification.

II. Dataset Development

A dataset of training data will be created using partner clinics, consisting of foot ulcerated and pre-ulcerated images, labeled by podiatry experts. Synthetic data augmentation will be used to correct dataset biases.

III. Model Training & Validation

The CNN model is optimized with transfer learning from pre-trained vision models. The models are tested with sensitivity, specificity, and ROC-AUC scores.

8. Proposed AI Framework

- **Step 1: Image Capture**

  The patients photograph both feet in controlled conditions with a thermal camera smartphone attachment.

- **Step 2: AI Analysis**

  The CNN translates images to detect temperature asymmetries of greater than clinical thresholds and produces a risk score.

- **Step 3: Clinician Review**

  Teleconsultation is aimed at high-risk patients in whom preventive treatment is started before ulceration.

- **Step 4: Continuous Monitoring**

  Reminders to patients for repeated scans allow for longitudinal follow-up of foot status.

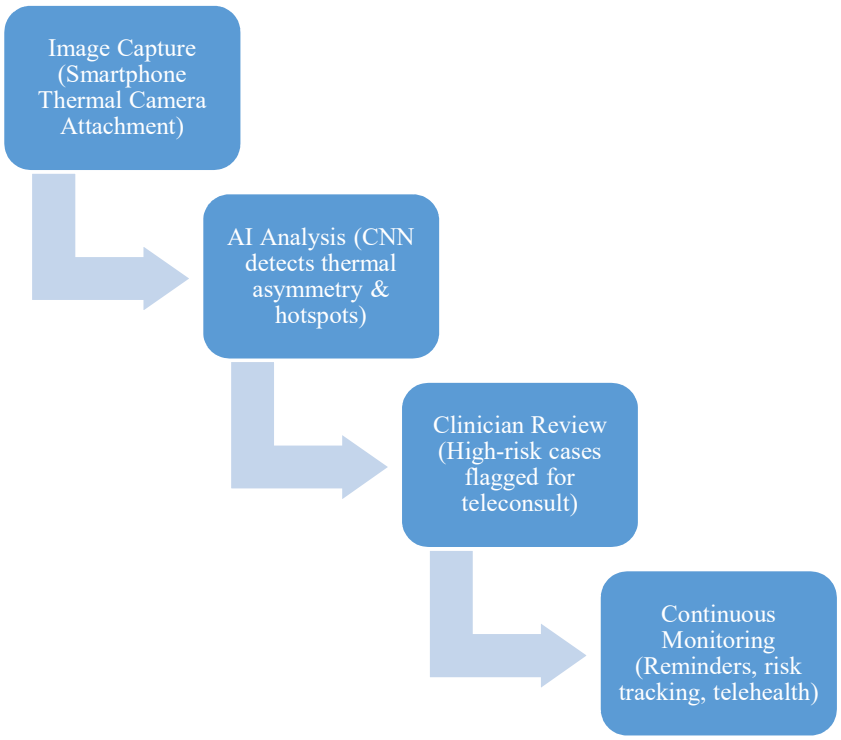

Figure 1. Proposed Framework for AI-Based Early Detection of DFU

9. Implementation Phase

- **Pilot Phase** – Roll-out within specific diabetes clinics with patient education.
- **Home Monitoring Rollout** – Deployment of devices to high-risk patients.
- **Integration with Health Records** – Automatic updating of patient EHR.
- **Scaling** – Deployment to rural health workers for community-based screening.

10. Expected Outcomes

- Preclinical identification of DFUs before evident ulceration.
- Amputation rate reduction of between 50% in high-risk groups.
- Increased access to preventive foot care services for the marginalized populations.
- This reduction in hospitalization saves the health system money.

11. Challenges and Mitigation

- **Data Privacy**: Use HIPAA/GDPR-compliant encryption.
- **Device Cost**: Register with device manufacturers for subsidized devices.
- **User Training**: Create multilingual training material.
- **Algorithm Bias**: Ensure dataset variety by including age, gender, and skin color.

12. Limitations

Despite its promising outlook, the said study faces several limitations:

- **Dataset Availability**: A broad and diverse dataset recorded by smart phones for diabetic foot thermal images is needed to be available. The generalizability of the model may be compromised by limited availability of such data.

- **Device Dependency**: Performance depending on the type and calibration of smartphone thermal imaging accessories, that affecting consistency.
- **Patient Compliance**: The ability of a patient to regularly scan themselves assumes appropriate training, motivation and compliance which might be harder in practice to achieve.
- **Clinical Validation**: The AI model absolutely requires stringent validation in various clinical contexts before widespread deployment can be recommended.
- **Bias and Fairness**: Thermal readings may be biased by a patient's skin type, foot size and shape, or environmental conditions.

13. Conclusion

This paper introduces a new AI-driven early diabetic foot ulcer diagnosis system via smartphone thermal imaging. Overcoming technology as well as access barriers, the system can revolutionize diabetic foot care, especially in low-resource settings. Integrating AI-powered image analysis with telemedicine guarantees preventive, timely treatment to high-risk patients, drastically cutting the global burden of diabetes-related amputations.

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