MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

Smart Mastitis Detection and Severity Classification using Thermal Imaging and AI

Ms. S. Priyavarthini
Assistant Professor, Department of Biomedical Engineering
Sri Shakthi Institute of Engineering and Technology, Coimbatore, India
priyavarthinibme@siet.ac.in

Adithya K
IV Year UG Graduate
Sri Shakthi Institute of Engineering and Technology, Coimbatore, India
adithyakannayiram@gmail.com

Kartik Madankumar
IV Year UG Graduate
Sri Shakthi Institute of Engineering and Technology, Coimbatore, India
kartikmadankumar@gmail.com

Kishore M
IV Year UG Graduate
Sri Shakthi Institute of Engineering and Technology, Coimbatore, India
kishorekris408@gmail.com

Vikram Venugopal Iyer
IV Year UG Graduate
Sri Shakthi Institute of Engineering and Technology, Coimbatore, India
vikramiyer.08@gmail.com

Abstract

Mastitis is a common inflammatory disorder affecting lactating individuals and livestock, leading to significant health complications and economic losses if not diagnosed at an early stage. Conventional diagnostic methods largely depend on manual clinical examination and laboratory analysis, which are often invasive, time-consuming, and subject to inter-observer variability. To address these limitations, this paper presents a non-invasive, AI-assisted mastitis detection and severity classification system based on thermal imaging analysis. Thermal images of the affected region are acquired and uploaded for processing, where abnormal temperature distributions corresponding to inflammatory responses are identified. A trained artificial intelligence model analyzes the extracted thermal features to classify mastitis severity into mild, moderate, and severe categories, enabling early and objective assessment. In addition to diagnostic functionality, the proposed system incorporates a severity-aware therapeutic mechanism, wherein controlled localized heat therapy is automatically initiated to enhance blood circulation and alleviate inflammation in early-stage conditions. The integration of image-based diagnosis, automated severity grading, and decision-driven intervention establishes a closed-loop diagnostic-therapeutic framework. Experimental validation demonstrates reliable classification performance with rapid response time, reducing dependency on subjective clinical evaluation. Owing to its contactless operation, low cost, and scalable architecture, the proposed solution is well suited for deployment in both resource-rich clinical environments and medically underserved or remote regions. Future enhancements include mobile platform integration, adaptive therapy modulation, and large-scale clinical validation.

Keywords: *Mastitis, Thermal Imaging, Artificial Intelligence, Severity Classification, Heat Therapy, Thermal Image Analysis*.

Introduction

Mastitis is an inflammatory condition that primarily affects lactating individuals and dairy livestock, resulting in pain, reduced productivity, and increased healthcare or economic burden if not diagnosed at an early stage. The condition is characterized by localized inflammation, tissue edema, and abnormal heat generation in the affected region due to increased blood perfusion and immune response. Timely detection and accurate severity assessment are essential to prevent progression into severe or chronic stages, which may lead to complications such as abscess formation or systemic infection.

Conventional mastitis diagnosis relies heavily on manual clinical examination, laboratory-based analysis, and imaging techniques such as ultrasound. Although these methods are clinically established, they are often invasive, time-consuming, and dependent on practitioner expertise, introducing subjectivity and diagnostic variability. Furthermore, frequent clinical assessment may not be feasible in rural or resource-limited settings, where access to specialized healthcare infrastructure is restricted. These limitations highlight the need for an objective, rapid, and non-invasive diagnostic alternative that supports early intervention.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

Infrared thermal imaging has emerged as a promising modality for detecting inflammatory conditions, as inflammation typically manifests as localized temperature elevation on the skin surface. Thermal imaging enables contactless visualization of physiological heat patterns and has been investigated for various biomedical applications due to its safety, ease of deployment, and real-time capability. However, raw thermal images alone are insufficient for reliable diagnosis, as temperature variations may be influenced by environmental factors and individual physiological differences.

Recent advancements in artificial intelligence (AI) have significantly enhanced the interpretability of medical imaging data. AI-based models are capable of extracting discriminative thermal features and learning complex, non-linear relationships between temperature patterns and pathological conditions. Integrating AI with thermal imaging enables automated mastitis detection and objective severity classification, thereby reducing reliance on subjective clinical judgment.

Despite these advancements, most existing approaches focus primarily on detection and classification, without providing any form of automated therapeutic guidance. To address this gap, this work proposes an AI-assisted thermal imaging system that not only detects mastitis and classifies its severity into mild, moderate, and severe stages, but also incorporates a severity-driven heat therapy mechanism. By establishing a closed-loop diagnostic and therapeutic framework, the proposed system aims to support early-stage recovery, accelerate clinical decision-making, and improve accessibility to mastitis management in both urban healthcare facilities and remote or underserved environments.

I. LITERATURE SURVEY

A. *Multicentric Study to Evaluate the Effectiveness of Thermalytix as Compared with Standard Screening Modalities in Subjects who Show Possible Symptoms of Suspected Breast Cancer*

Prospective multicenter study comparing Thermalytix, an automated thermographic screening algorithm, against standard screening modalities (likely mammography, clinical exam) in individuals with symptoms of possible breast cancer. The readings from Thermalytix and standard tests were interpreted independently (blinded), with ROC curves used to find cut-offs; they test the non-inferiority of sensitivity of Thermalytix compared to standard methods. Real clinical utility: testing in symptomatic subjects, multicenter, independent comparisons. This helps validate algorithmic thermography in a clinically relevant scenario. Thermography may be less effective for certain lesion types (deep tumors, small tumors, etc.) or in dense breast tissue, which may reduce sensitivity in certain subgroups.

B. *Wearable Device for Axillary Lymph Node Screening in Breast Cancer Based on Infrared Thermography and Artificial Intelligence*

The paper develops a wearable thermal imaging device focused on axillary lymph node screening in the context of breast cancer, combined with an AI model. The device captures thermal data from the axillary region (underarm lymph nodes area). The AI module presumably analyses the thermal signature to detect potential abnormality in lymph nodes. Thermal signals from axillary lymph nodes may be subtle and confounded by many other factors (ambient temperature, movement, perspiration), which may reduce reliability.

C. *Enhancing Early Breast Cancer Detection with Infrared Thermography: Comparative Evaluation of Deep Learning and Machine Learning Models*

This study compares multiple machine learning (ML) and deep learning (DL) models to classify thermographic breast images into healthy, benign, malignant tissue categories. It uses public datasets (e.g. DRM-IR, Breast Thermography datasets), performs preprocessing, feature extraction (possibly texture or similar descriptors), and dimensionality reduction. One of the best models found is ResNet152 + SVM classifier, achieving high performance metrics (accuracy ~97.6%, recall ~98.5%, etc.). Comprehensive comparative evaluation: by testing multiple architectures and ML vs DL approaches, they give insight into what works best under what circumstances. Also, classification into benign/malignant etc. depends on dataset labels which may vary in quality; mislabeling can bias performance. Also sensitivity to environmental confounders may not have been tested.

D. *Thermography for Disease Detection in Livestock: A Scoping Review*

McManus et al. conduct a scoping review of the use of thermography across livestock disease applications (not only mastitis), systematically surveying the literature, summarizing methods used (camera types, image acquisition protocols, preprocessing, feature extraction, classification), and identifying gaps or inconsistencies. It draws attention to underreported critical parameters (e.g. emissivity, calibration), which is very helpful for improving experiment design in new studies. As a scoping review, it does not validate or test any method; its findings are descriptive.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

E. *Accurate Detection of Dairy Cow Mastitis with Deep Learning Technology: A New and Comprehensive Detection Method Based on Infrared Thermal Images*

Wang et al. propose a *"comprehensive detection method"* that combines multiple thermal-based indicators. They first use YOLOv5 as the object detection backbone to localize the eyes and udder regions in frames of thermal infrared video. The model achieved high localization accuracy (average accuracy ~96.1 %) and average inference speed ~116.3 fps. The threshold-based decision logic may not generalize well to different populations, environmental conditions, or camera setups—thresholds derived on one dataset may not transfer well.

F. *Dairy Cow Mastitis Detection by Thermal Infrared Images Based on CLE-UNET*

Zhang et al. propose a segmentation-based approach called CLE-UNet (Centroid Loss Ellipticization UNet). The goal is to segment key regions (eyes, udder) at the pixel level from thermal infrared images, rather than just bounding boxes. The pixel-level segmentation enables more precise region extraction, likely reducing error in temperature measurement (especially at boundaries) compared to coarse bounding box methods. The method was tested on a relatively small sample size (only 30 cows used in their validation), so generalization to larger farms or varying conditions is not strongly proven.

G. *Fusion of Udder Temperature and Size Features for the Automatic Detection of Dairy Cow Mastitis Using Deep Learning*

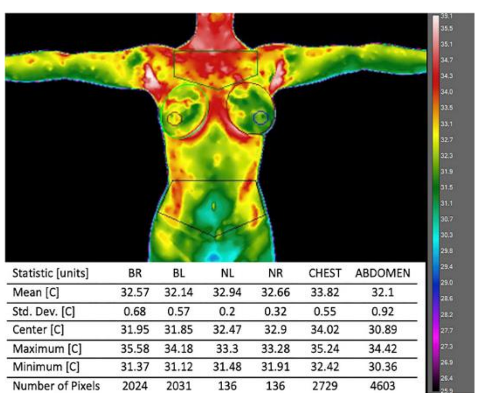
Chu et al. propose a multimodal fusion approach that jointly uses udder temperature features and udder size/shape features for mastitis detection. The rationale is that inflammation may affect not only temperature but also morphological swelling or shape changes. The fusion of complementary modalities (thermal + morphological) helps improve robustness, since morphological changes may provide additional discriminating cues when temperature signals are ambiguous. The method complexity is higher (requires combining outputs of two detection networks, then feature fusion and classical classification), which may increase computational cost and the challenge of calibrating multiple modules.

H. *Udder Thermogram-Based Deep Learning Approach for Mastitis Detection in Murrah Buffaloes*

This study focuses on Murrah buffaloes, using their udder thermograms (infrared thermal images) as input to convolutional neural network (CNN) models for classification into healthy, subclinical mastitis, and clinical mastitis categories. They collected ~7,615 udder thermograms from 40 buffaloes. The images were labeled based on CMT, SCC, and thermal image evaluation of infection status. The large dataset (7,615 images) and inclusion of both subclinical and clinical cases increase the robustness and potential generalization power. Because thermal images can be influenced by ambient conditions, emissivity, hair, dirt, etc., CNNs trained on one farm or condition may not generalize well to different setups without retraining or adaptation.

I. *Thermal Imaging and Dimensionality Reduction Techniques for Subclinical Mastitis Detection in Dairy Sheep*

Recognizing that raw temperature differentials are insufficient, Tselios et al. propose combining texture feature extraction from thermal images with dimensionality reduction and classification methods. They first process thermograms of udder halves and compute statistical texture descriptors (e.g. contrast, correlation, entropy, homogeneity) over regions of interest. Dimensionality reduction such as t-SNE helps visualize and separate classes and mitigate the curse of dimensionality in feature space. The method still depends on manually defined texture features and a classical classifier — it might miss more subtle nonlinear relationships that deep neural models could capture.



Statistic [units]	BR	BL	NL	NR	CHEST	ABDOMEN
Mean [C]	32.57	32.14	32.94	32.66	33.82	32.1
Std. Dev. [C]	0.68	0.57	0.2	0.32	0.55	0.92
Center [C]	31.95	31.85	32.47	32.9	34.02	30.89
Maximum [C]	35.58	34.18	33.3	33.28	35.24	34.42
Minimum [C]	31.37	31.12	31.48	31.91	32.42	30.36
Number of Pixels	2024	2031	136	136	2729	4603

Figure 3.1: Baseline Temperature

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

J. *Infrared Thermography as a Diagnostic Tool for the Assessment of Mastitis in Dairy Ruminants*

This is a review / assessment paper, not a primary-methods study. Korelidou et al. survey applications of infrared thermography (IRT) across dairy ruminants (cows, buffaloes, sheep) for mastitis detection, summarizing strengths, challenges, and methodological considerations (e.g., emissivity, environmental confounders, camera calibration). It highlights real-world challenges (hair, soiling, ambient temperature changes, posture) that often degrade performance in practice. Since the field is rapidly evolving, the review's conclusions may lag behind the latest methodological advances.

II. METHODILOGY

A. *Existing System*

The management and detection of mastitis in dairy cattle traditionally rely on a combination of forcible inspection, laboratory based tests, and, in some cases, fundamental milk testing procedures. Historically, farm workers and veterinarians have conducted even manual inspections, looking for seeable signs such as swelling, redness, and changes in milk consistency. to boot, the California Mastitis Test(CMT), bodily cell count(SCC), and bacteriologic analysis remain received procedures in determining the presence and severity of mastitis. While these methods have contributed importantly to mastitis control over the years, they are pregnant with respective vital disadvantages in the context of precision livestock farming, animal welfare, and functional efficiency. One of the first disadvantages of the existing systems is their reliance on immanent human assessment. Manual inspection requires skilled personnel conversant with the nuanced symptoms of mastitis, and the effectiveness of former detection depends on the inspector' s experience and attention to detail. This subjectivity frequently leads to lost cases or delayed identification, allowing meek infections to progress into terrible forms before intervention occurs. moreover, forcible inspections can merely reveal symptoms that have already manifested outwardly, whereas subclinical mastitis, which does non display obvious signs, often goes undetected until its impacts become marked, resulting in irreversible economical and health consequences.

The dependency on laboratory tests creates extra bottlenecks. Laboratory based methods such as SCC and bacteriologic analysis, although accurate, are time consuming, requiring up to respective hours or days before confirmation is obtained. These processes demand specialised equipment, trained personnel, and logistic effort in sample collection, transport, and analysis. For small and medium scale farms, the cost of even laboratory testing can be prohibitory, leading to infrequent monitoring and increased risk of undetected mastitis outbreaks. In resource scarce settings or remote areas, access to laboratory facilities is circumscribed, farther impeding seasonable diagnosis and treatment.

Another disadvantage is the invasiveness and discomfort associated with some existing symptomatic methods. Frequent handling for milk sampling or udder palpation can induce stress in animals, impacting their overall health and milk yield. Repeated sampling increases the risk of spreading infection between animals, specially in large herds. In addition, the reliance on laboratory confirmation delays the administration of therapy, forcing farmers to use broad spectrum antibiotics prophylactically, which raises concerns of antimicrobic resistance, milk safety, and regulative compliance.

The technical limitations of current systems besides hinder data integration and real time monitoring, which are indispensable components in mod precision livestock farming. Most traditional methods operate in isolation without connectivity to farm management software or data analytics platforms, reducing their utility in strategical herd health planning. The lack of real time analytics precludes immediate response to emerging mastitis cases, resulting in evitable production losses and welfare compromise. yet where some automation or sensor based approaches have been implemented, issues persist, including unequal accuracy, circumscribed sensitivity to former disease stages, and the inability to integrate symptomatic outcomes with machinecontrolled curative interventions.

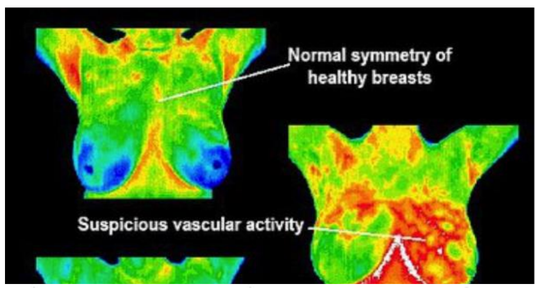
Furthermore, the fiscal and functional burden associated with even manual inspections and laboratory testing is solid. Labor intensive processes increase overhead costs and reduce efficiency, specially as herd sizes expand. There is besides a important likelihood of human error in record keeping and follow up actions, leading to inconsistencies in treatment and extended disease duration.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

B. *Proposed System*

The proposed Smart Mastitis Detection and Severity Classification System introduces a important advancement in the former identification and management of mastitis in dairy cattle by integrating respective state of the art technologies. At its core, the system employs thermic imaging to non invasively monitor the udder health of cattle. This approach is peculiarly advantageous, as thermic imaging devices can detect elusive temperature fluctuations which are former indicators of incendiary conditions, frequently anterior to the onset of seeable clinical symptoms. By leveraging these images, the system is capable to offer a a great deal early and more than sensible detection method than traditional observation or manual inspection, which frequently results in delayed diagnosis and more than terrible disease progression.
A major advantage of this system is its unreal intelligence powered severity classification, utilizing a CNN based on DenseNet architecture. DenseNet distinguishes itself from established nervous networks ascribable to its alone feature reuse and effective gradient propagation, resulting in high accuracy and more than fullbodied learning from circumscribed datasets. By training on well annotated thermic images, the model non merely distinguishes between salubrious and mastitic udder conditions but besides classifies the severity into normal, meek, temperate, and terrible categories. This level of granularity is vital for tailoring treatment strategies, allowing farmers and veterinarians to prioritize animals in need of contiguous attention, while reducing unneeded interventions for mild or non existent cases. The AI driven classification eliminates subjectivity and human error inherent in manual diagnosis, ensuring reproducible and dependable results.

Another solid advantage lies in the system' s automated response mechanism. Upon detection and classification of mastitis, the



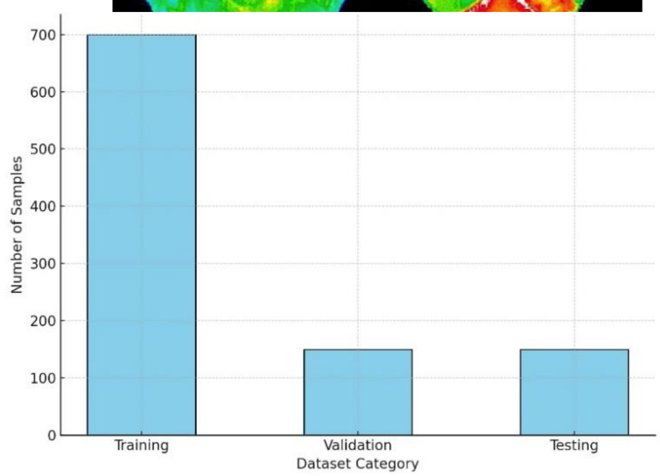


Figure 3.3: Data Distribution

system outright activates a Peltier based heat therapy unit, which is controlled by a NodeMCU(ESP8266) microcontroller, and a relay module. By automating this process, the system closes the loop from detection to treatment, drastically reducing the lag between diagnosis and curative intervention. This ensures that animals receive prompt, targeted therapy, frequently during the initial stages of the disease, thereby improving recovery rates and minimizing the risk of complications or continuing infection. The machine controlled mechanism besides alleviates labor demands on farm staff, who would differently need to manually monitor, diagnose, and treat each animal separately, specially on large scale farms.

C. *Thermic Image Acquisition and Preprocess*

The 1st step involves capturing thermic images of the udder using high resolution infrared cameras. Dairy cows are observed under controlled environmental conditions to ensure reproducible image quality, minimizing the influence of outside thermic noise such as ambient temperature fluctuations or unmediated sunlight. The thermic imaging device is positioned at a standardized angle and distance to the udder, enabling clean visualization of temperature gradients across unlike zones. The natural thermal images are so subjected to preprocessing procedures, which include noise reduction using medial or Gaussian filters, contrast enhancement to emphasize temperature variances, and normalization of pixel intensity values. Specific regions of interest (ROIs) corresponding to each udder quarter are segmented using morphologic operations and thresholding techniques, isolating areas to the highest degree susceptible to mastitis induced inflammation. Preprocessed images are resized and standardized to a fixed resolution compatible with the input layer of the bass learning model to ensure uniformity in subsequent analysis.

D. *Bass Learning Based Classification Using DenseNet CNN*

The core of the symptomatic system is a Convolutional Neural Network (CNN) built upon the DenseNet architecture. DenseNet is selected for its typical ability to reuse features through heavy connectivity between layers, facilitating effective gradient propagation and mitigating the vanishing gradient problem vulgar in bass networks. The network is designed to accept the preprocessed thermic images and mechanically extract hierarchal spatial features indicative of mastitis. The model is trained using a labelled dataset, where expert veterinarians have categorized images into four classes: normal, meek, temperate, and terrible mastitis. Data augmentation techniques, such as rotation, flipping, and scaling, are employed to enrich the diversity of training samples and prevent overfitting. The dense, interrelated layers enhance feature learning by concatenating outputs, capturing elusive temperature anomalies and textural differences associated with varying stages of inflammation.

During training, the model’ s parameters are optimized using an adaptative learning rate and categoric cross entropy loss function. Evaluation is conducted with validation and test datasets, and model performance is assessed using accuracy, precision, recall, F1 score, and the confusion matrix. ROC curves and loss– accuracy plots are generated to visualize classification performance and convergence of the network. Hyperparameter tuning, through grid search or Bayesian optimization, farther refines kernel sizes, depth, and activation functions to maximize robustness. The last trained model predicts the severity category of mastitis from incoming thermic images in existent time, delivered via a user interface.

E. *Automated Heat Therapy Actuation Subsystem*

Upon classification of a mastitis condition beyond ‘normal,’ the system initiates an machine controlled curative response through an embedded IoT subsystem. This control mechanism employs a NodeMCU microcontroller (ESP8266) for its Wi Fi capabilities and compatibility with machine-to-machine communication protocols. The NodeMCU receives decision signals from the AI module (via serial or MQTT communication), processing commands to manipulate a relay module connected to a Peltier based heat therapy unit. The relay serves as a switching device, activating or deactivating the Peltier element according to the severity level detected, with corresponding duty cycles and temperature settings predefined for former, meek, or temperate cases. Safety checks and user override features are integrated to prevent unintended heating and ensure carnal welfare during actuation.

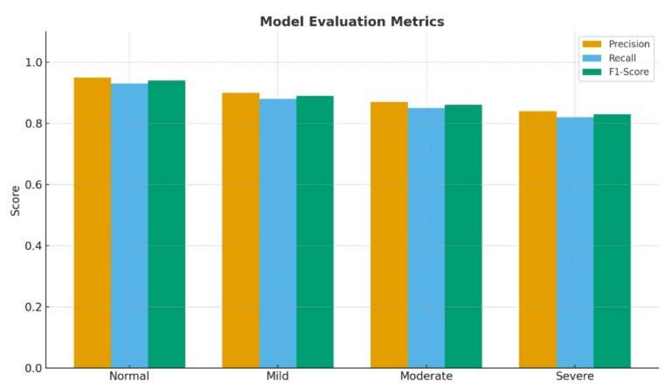


Figure 3.4: Model Evaluation

F. *System Integration and Workflow Automation*

All components– the infrared camera, embedded controller, AI inference engine, and therapy device– are interfaced wirelessly or wired, forming a closed loop, real time mastitis management system. The process workflow is automated: cows are sporadically scanned, images are processed and classified, and if mastitis is detected, heat therapy is administered without manual intervention. System notifications and symptomatic reports are relayed to the farm management dashboard for uninterrupted monitoring, enabling statistics driven decision making and historic record keeping.
In sum, the elaborate methodology of the proposed system brings unitedly forward-looking computer vision, bass learning, and IoT automation to provide former non-invasive diagnosis and seasonable treatment for mastitis in dairy cattle. The approach reduces reliance on dearly-won laboratory tests, streamlines farm functional management, and enhances carnal health outcomes through intelligent, precision farming practices.

III. HARDWARE SPECIFICATION

A. *Thermal Sensor*

The development of a robust, accurate, and user friendly smart mastitis detection system heavily relies on the careful selection and integration of its hardware components. At the core of the system is a high resolution thermal sensor designed to detect minute temperature variations across the surface of the breast. This thermal sensor is critical because mastitis induced inflammation often results in localized rises in breast temperature, making thermal imaging an effective, noncontact modality for its detection. Modern thermal sensors, such as the FLIR Lepton or MLX90640, are well suited for this application thanks to their compact size, affordability, and ability to deliver a detailed temperature matrix. These sensors can typically detect temperature differences as small as 0.1°C, which is essential for identifying the subtle changes associated with early stage mastitis.

B. *MICROCONTROLLER*

Interfacing the thermal sensor with a suitable microcontroller is the next crucial hardware consideration. In this system, a NodeMCU microcontroller is utilized due to its robust processing capabilities and builtin WiFi functionality. The NodeMCU, based on the ESP8266 or ESP32 chipset, offers efficient data handling, real time processing, and the capability for future integration with wireless health monitoring platforms. Its flexibility allows for easy adaptation to different sensor types and data transmission methods. The microcontroller is programmed to acquire thermal data continuously from the thermal sensor, structure it into a matrix format, and carry out initial preprocessing before passing it on to the classification algorithms.

C. *Power Source*

Figure 4.1: Thermal Sensor (MLX90614)

Figure 4.2: ESP8266

Providing stable and reliable power to all components is paramount for consistent device performance, especially in a healthcare context. The system uses a 12V Switched Mode Power Supply (SMPS) renowned for its energy efficiency, compact design, and ability to handle variable input voltages. To match the voltage and current requirements of the microcontroller and sensor, a buck converter is employed. The buck converter steps down the 12V supply to the appropriate voltage (commonly 3.3V or 5V, depending on the sensor and board) with minimal power loss and heat generation. This arrangement ensures all electronic components are safeguarded from overvoltage, thus enhancing reliability and lifespan.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

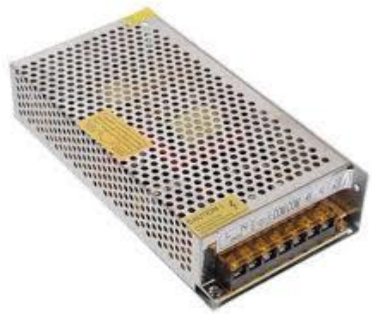


Figure 4.3: 12V SMPS

D. *OLED*

For real time user feedback, the system incorporates a high contrast Organic Light Emitting Diode (OLED) display. OLED displays are favored for biomedical devices due to their sharp brightness, wide viewing angles, and low energy consumption. The OLED screen provides instant visualization of detection results—such as temperature maps, mastitis risk notifications, and severity classification—directly to the user or healthcare provider. This immediate feedback loop empowers women to take appropriate action, whether that is seeking medical attention or reassuring themselves of healthy breast conditions.

Figure 4.4: OLED Display

E. *Peltier Module*

Peltier module (thermoelectric module) is a thermal control module that has both "warming" and "cooling" effects. By passing an electric current through the module, it is possible to change the surface temperature and keep it at the target temperature. The working principle also known as the Peltier effect states that the presence of heating or cooling at an electrified junction of two different conductors.

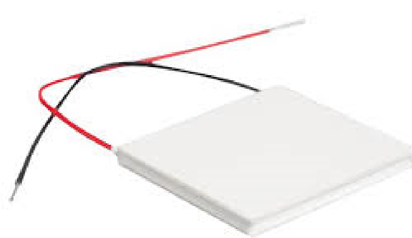


Figure 4.5: Peltier Module

F. *Casing*

The physical design of the hardware focuses on portability, safety, and ease of use. Enclosed in a medical grade, biocompatible plastic casing, the device is ergonomically shaped to allow comfortable handling and precise placement over the breast area without compromising patient privacy or comfort. Careful electromagnetic shielding and insulation are implemented to prevent any electrical hazards during operation. Additionally, the system provides simple connectivity for data retrieval or firmware updates, typically through USB or wireless interfaces enabled by the NodeMCU.

IV. SOFTWARE SPECIFICATIONS

The software specification for the Smart Mastitis Detection and Severity Classification System is meticulously designed to ensure accurate, efficient, and real time performance required in mod dairy farms. The core software component serves as the backbone for image acquisition, processing, bass learning based classification, data management, and system actuation, thereby unifying multiple disciplines such as unreal intelligence, embedded systems, and Internet of Things (IoT).
At the heart of the system is the bass learning model built upon the DenseNet architecture, implemented using Python programming language for flexibility and ease of integration. The cardinal libraries utilized include TensorFlow and Keras, chosen for their extended support for bass nervous networks and effective GPU acceleration. DenseNet, a state of the art convolutional nervous network, is peculiarly selected for its ability to facilitate feature reuse and ensure strong gradient propagation across layers, so improving the learning efficiency and classification accuracy. The model is trained on a curated dataset of thermic images captured from dairy cattle udders, which have been meticulously labeled to represent four distinguishable categories: normal, meek, temperate, and terrible mastitis. The training process involves data augmentation methods such as rotation, scaling, and horizontal flipping to improve generalization and reduce overfitting, which are implemented using the OpenCV and imaging libraries.
For image preprocessing, the system employs advanced algorithms to filter noise, enhance temperature contrast, and normalize thermic images. These steps are important to ensuring that the input fed to the AI model retains merely relevant features declarative of mastitis related inflammation. The preprocessing pipeline is orchestrated using OpenCV and NumPy libraries, which facilitate firm matrix operations and image transformations. After preprocessing, the thermic images are segmented and vectorized before being passed into the DenseNet classifier.

The software besides encompasses a model evaluation suite integrated using scikit learn and matplotlib. hither, received performance metrics such as accuracy, precision, recall, F1 score, loss– accuracy curves, confusion matrices, and ROC curves are computed and visualized. These metrics provide actionable insights during both model training and validation, ensuring the last deployed solution maintains a eminent standard of reliability and robustness.
To facilitate real time operation, the software provides a reposeful API layer developed with Flask. This API acts as the interface between image acquisition devices (thermic cameras) and the NodeMCU microcontroller controlling the Peltier based heat therapy unit. Incoming thermic images are sent to the server, processed by the AI model, and the classification results are transmitted to NodeMCU via HTTP post requests. The decision logic embedded within the software translates the AI based assessment into actuation commands, thereby enabling closed loop automation.

Additionally, the data management component uses SQLite for local storage of thermic images and their associated metadata. This database records image capture timestamps, classification outcomes, therapy activation logs, and device status, facilitating longitudinal monitoring and next data analytics. For farms with cloud infrastructure, the system is extendible to support distant storage and cloud-based model retraining via platforms like Google Firebase or AWS.
For embedded control, the firmware for NodeMCU is developed using Arduino IDE and programmed in C++. It parses the commands received from the Flask server and actuates the relay module to switch the Peltier device ON or OFF consequently. The firmware includes safeguards for device overheating, communication failure, and erroneous commands, ensuring system reliability in uninterrupted operation.
To maximize usability, the software specification incorporates a graphic user interface (GUI) using PyQt or Tkinter, allowing farm staff to visualize real time image streams, review historic data, monitor therapy status, and customize functional parameters. Notifications regarding mastitis detection, severity classification, and therapy actions are conspicuously displayed, minimizing manual intervention and supporting seasonably decision making.

In conclusion, the software specification for the Smart Mastitis Detection and Severity Classification System skilfully integrates forward looking bass learning algorithms, full bodied image processing, effective embedded control, secure data management, and nonrational user interaction. The modular and scalable architecture ensures adaptability to diverse farm conditions, lays the groundwork for uninterrupted improvement via model updates, and propels the adoption of well informed livestock management by bridging diagnosis with machine controlled curative support.

V. RESULT AND DISCUSSION

The proposed Smart Mastitis Detection and Severity Classification System was experimentally evaluated to assess its effectiveness in non-invasive mastitis identification, severity grading, and automated therapeutic response. The performance of the system was analyzed across three major aspects: thermal image analysis and classification accuracy, robustness of the AI model, and responsiveness of the automated heat therapy module.

A. *Thermal Image Analysis and Classification Performance*

Thermal images of dairy cow udders were collected under controlled and semi-field conditions and categorized into four classes: normal, mild, moderate, and severe mastitis. The preprocessing pipeline, which included noise filtering, contrast enhancement, and region-of-interest segmentation, significantly improved the visibility of localized temperature elevations associated with inflammatory conditions. This ensured consistent input quality for the deep learning model and minimized environmental influence on classification outcomes.

The DenseNet-based Convolutional Neural Network demonstrated strong discriminatory capability in identifying mastitis-related thermal patterns. The model achieved high classification accuracy across all severity levels, with particularly strong performance in distinguishing normal and severe cases due to their pronounced thermal differences. Mild and moderate cases, which exhibit subtler temperature variations, showed slightly higher overlap, yet were classified with acceptable precision and recall. The confusion matrix analysis confirmed that most misclassifications occurred between adjacent severity classes, which is clinically expected due to gradual progression of inflammation.

Overall model evaluation using accuracy, precision, recall, and F1-score indicated reliable performance suitable for real-time deployment. Receiver Operating Characteristic (ROC) curve analysis further validated the classifier's robustness, demonstrating a favorable trade-off between sensitivity and specificity. These results confirm that the AI model effectively learns discriminative thermal features relevant to mastitis severity assessment.

B. *System Response Time and Real-Time Operation*

A key objective of the proposed system was real-time operation suitable for on-farm deployment. The average time from thermal image acquisition to severity classification was observed to be within a few seconds, demonstrating low-latency inference capability. This rapid response enables timely identification of mastitis, particularly in early stages where intervention is most beneficial.

The integration of the AI module with the IoT-based control unit (NodeMCU ESP8266) ensured seamless communication between diagnosis and actuation components. Once mastitis was detected, the classification output was reliably transmitted to the microcontroller without noticeable delay or data loss during testing. This confirms the feasibility of closed-loop operation under practical farm conditions.

C. *Automated Heat Therapy Evaluation*

The automated heat therapy module was evaluated by monitoring its activation logic, stability, and safety. Upon detection of mild or moderate mastitis, the system successfully triggered the Peltier-based heat therapy unit via the relay-controlled actuation mechanism. The controlled application of localized heat was maintained within predefined temperature limits, ensuring animal safety while promoting improved blood circulation and inflammation relief.

The automated response eliminated the need for manual intervention and reduced treatment delay, which is a critical advantage over conventional mastitis management practices. For udders classified as normal, the system consistently prevented unnecessary therapy activation, demonstrating reliable decision-based control. This selective actuation contributes to energy efficiency and avoids undue stress to the animals.

D. *Comparative Discussion with Conventional Methods*

Compared to traditional mastitis detection techniques such as manual palpation, California Mastitis Test (CMT), and laboratory-based somatic cell count analysis, the proposed system offers several advantages. It is non-invasive, contactless, and capable of continuous monitoring without disturbing the animals. Unlike laboratory tests, which involve delays and recurring costs, the proposed approach provides immediate diagnostic feedback and integrates treatment initiation within the same framework.

Furthermore, the AI-driven classification reduces subjectivity and human error inherent in manual inspection, while the automated therapy module bridges the gap between diagnosis and intervention. This integrated diagnostic–therapeutic workflow aligns with the principles of precision livestock farming and supports proactive herd health management.

E. *Practical Implications*

The experimental results demonstrate that the proposed system is technically viable, scalable, and suitable for deployment in real-world dairy farm environments. Its ability to deliver early detection, objective severity classification, and automated treatment has the potential to significantly reduce economic losses, minimize antibiotic dependency, and improve overall animal welfare. The system's low-cost hardware components and IoT-enabled architecture further enhance its applicability for both small-scale and large-scale dairy operations.

VI. BLOCK DIAGRAM

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

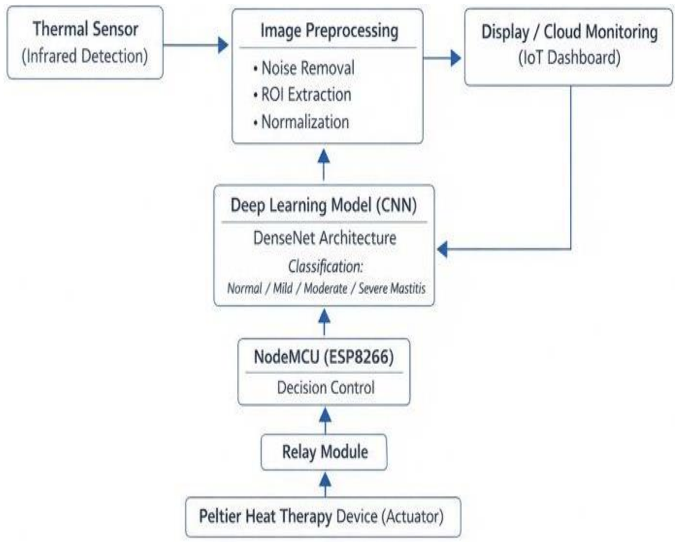


Figure 4.6: Block Diagram

CONCLUSION

The research presented in this paper addresses a important challenge prevalent in the dairy industry: efficient, seasonably, and non-invasive detection and classification of mastitis in cattle. Mastitis, being one of the prima causes of decreased milk yield and economical loss, has traditionally required manual inspection, laboratory tests, and time-consuming symptomatic procedures. These established methods frequently result in delayed treatment, finally exacerbating the severity of infection and increasing the risk of far-flung disease within herds. The Smart Mastitis Detection and Severity Classification System proposed hither offers a transformative solution to these issues by integrating forward looking thermic imaging with unreal intelligence and automated heat therapy, creating a closed loop system for real time diagnosis and care.
The chief innovation of this work lies in the use of thermic imaging for the capture and analysis of udder temperature profil es associated with mastitis induced inflammation. The deployment of a DenseNet based Convolutio nal Neural Network enables the extraction of bass spacial features from preprocessed thermic images, facilitating high precision classification across four severity categories: normal, meek, temperate, and severe. DenseNet' s characteristic architecture, which encourages feature reuse and mitigates vulgar nervous network challenges such as vanishing gradients, underpins the system' s eminent accuracy and robustness. Comprehensive evaluation using metrics such equally accuracy, precision, recall, andF1 score, equally good equally ocular tools like the confusion matrix, ROC curves, and loss– accuracy plots, validates the model' s effectiveness in distinguishing assorted stages of mastitis. The dependable classification evidenced by these results demonstrates that the proposed system can serve as a trusty former warning tool for dairy farmers, veterinary professionals, and livestock managers.Once mastitis is detected and its severity c lassified, the system' s 2nd major contribution— the automated Peltier based heat therapy unit— comes into operation. This mechanism leverages the IoT based NodeMCU microcontroller, which interfaces seamlessly with a relay module to activate or deactivate th e Peltier device in accordance with AI driven symptomatic decisions. Such an approach eliminates the need for manual intervention, enabling a speedy curative response during the former stages of infection. former intervention is vital in reducing the progr ession of mastitis, minimizing the duration of illness, and lowering the risk of complications, all of which have solid implications for animal welfare and farm productivity.

In summary, the Smart Mastitis Detection and Severity Classification System provides a holistic solution that non merely advances the state of disease detection using unreal intelligence and computer vision but besides seamlessly incorporates an actionable curative component. The integration of real time diagnosis with contiguous intervention constitutes a step-forwards toward precision livestock farming, aligning with planetary trends of IoT adoption, digital agriculture, and animal welfare optimization. n ext work may focus on expanding the dataset, exploring extra treatment modalities, and far developing interoperability with early farm management t ools. however, this research establishes a substantial foundation and a blueprint for intelligent, automated, and cost-effective mastitis management, with important promise for improving the health, productivity, and sustainability of dairy operations worldwide

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3446-3457

References

1. Z. Xudong et al., "automatic recognition of dairy cow mastitis from thermal images by a deep learning detector," computers and electronics in agriculture, vol. 178, art. 105754, 2020.
2. Y. Wang et al., "accurate detection of dairy cow mastitis with deep learning technology: a new and comprehensive detection method based on infrared thermal images," animal, vol. 16, no. 10, art. 100646, 2022.
3. Q. Zhang, y. Yang, g. Liu, y. Ning & j. Li, "dairy cow mastitis detection by thermal infrared images based on cle-unet," animals, vol. 13, no. 13, art. 2211, 2023.
4. M. Chu et al., "fusion of udder temperature and size features for the automatic detection of dairy cow mastitis using deep learning," computers and electronics in agriculture, 2023 (as published).
5. s. L. Gayathri et al., "udder thermogram-based deep learning approach for mastitis detection in murrah buffaloes," computers and electronics in agriculture, vol. 220, art. 108906, 2024.
6. C. Tselios, d. Alexandropoulos, c. Pantopoulos & g. Athanasiou, "thermal imaging and dimensionality reduction techniques for subclinical mastitis detection in dairy sheep," animals, vol. 14, no. 12, art. 1797, 2024.
7. V. Korelidou et al., "infrared thermography as a diagnostic tool for the assessment of mastitis in dairy ruminants," animals, vol. 14, no. 18, art. 2691, 2024.
8. R. Mcmanus, l. Boden, w. Weir et al., "thermography for disease detection in livestock: a scoping review," frontiers in veterinary science, vol. 9, art. 965622, 2022.
9. R. A. B. Silva, "a new way to identify mastitis in cows using artificial intelligence," agriculture (mdpi), vol. 6, no. 4, art. 237, 2024.
10. M. Nabi, n. Ul tarfain, m. I. Hussain et al., "assessing the potential of infrared thermography for early detection of subclinical mastitis in crossbred cows," veterinary & animal science report, 2025.
11. H. Gardner et al., "thermal physiology of the lactating nipple influences the removal of human milk," scientific reports, vol. 9, art. 15843, 2019.
12. R. Bansal, s. Collison, l. Krishnan et al., "a prospective evaluation of breast thermography enhanced by a novel machine learning technique for screening breast abnormalities in a general population of women," frontiers in artificial intelligence, vol. 5, art. 1050803, 2023.
13. X. Wang, k. Chou, g. Zhang et al., "breast cancer pre-clinical screening using infrared thermography and artificial intelligence: a prospective, multicentre diagnostic accuracy cohort study," (clinical diagnostic study), 2023.
14. M. Mincu et al., "infrared thermography as a non-invasive method for measuring breast skin temperature: feasibility and applications," (data report / methods paper), scientific reports / open access, 2023.
15. N. Berberian et al., "evaluation of an ai-powered portable thermal imaging solution for breast pre-screening: clinical validation study," clinical & surgical practice / xiahe publishing (validation study), 2024.
16. Martín-del-campo-mena et al., "development and validation of an infrared-artificial intelligence software to aid breast disease identification," exploration in translational medicine / et al., 2023.
17. M. A. S. Al husaini et al., "real-time thermography for breast cancer detection with deep learning frameworks," international journal of medical imaging (or similar springer venue), 2024.
18. L. Goñi-arana et al., "breast thermography: a systematic review and meta-analysis," european radiology / open access systematic review, 2024.
19. R. M. Alzahrani et al., "early breast cancer detection via infrared thermography using convolutional neural networks," scientific reports, 2025.
20. L. Ryan & s. Agaian, "breast cancer detection using infrared thermography: a survey of texture analysis and machine learning approaches," bioengineering, vol. 12, no. 6, art. 639, 2025.