

Thermal infrared and visible data acquisition system for postoperative wound healing monitoring

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Abstract—Infrared thermography is a non-invasive imaging method that enables the assessment of physiological processes in tissues by recording surface temperature distribution. This paper presents a portable system for standardized acquisition of thermal and RGB images, designed to support the monitoring of postoperative wound healing. The device is based on a Raspberry Pi 5 minicomputer, a Pi Camera 3 visible-light camera, and a FLIR Lepton 3.5 thermal camera. A key element of the system is a geometric registration procedure that maps the thermal data into the RGB image coordinate system. The registration is supported by a dedicated board containing four reference points in the form of heat sources (light bulbs) simultaneously visible in both imaging modalities. Based on the determined region of interest (ROI) and surrounding ring area (RING), statistical and dynamic features describing temperature distribution within the wound and its surroundings are extracted. The described solution ensures repeatability and standardization of measurement, which is a necessary condition for further quantitative analysis of the healing process.

Keywords—infrared thermography; wound healing; RGB–LWIR registration; affine transformation; Raspberry Pi; FLIR Lepton; medical data acquisition; image processing

I. INTRODUCTION

INFRARED thermography is a non-invasive imaging method that uses detection of electromagnetic radiation emitted by the human body in the wavelength range of 8–14 μm (long-wave infrared, LWIR). Every body above absolute zero emits thermal radiation according to the Stefan–Boltzmann law; for biological tissues the emissivity is typically $\varepsilon \approx 0.98$, making them close to perfect blackbodies in this spectral range [4].

The result of the recording is a thermogram – a two-dimensional map of skin surface temperature distribution that indirectly reflects physiological processes such as blood perfusion, metabolic activity, and inflammatory response [1], [23]. Due to its non-invasiveness, absence of ionizing radiation, and suitability for continuous monitoring, thermography is gaining increasing interest in clinical diagnostics [2], [22].

Particular importance is attributed to the use of thermography in monitoring chronic and postoperative wounds. Elevated

temperature within a wound correlates with increased inflammation or infection, while local hypothermia may indicate vascular disturbances and tissue ischemia [5], [25]. Studies suggest that temperature differences between the wound and surrounding healthy tissue can be a valuable quantitative indicator of healing status [6], [24]. In the context of diabetic foot, thermography is applied as an early detection tool for inflammatory conditions, before visible skin changes appear [3], [7].

The increasing availability of compact thermal cameras based on uncooled microbolometers [8] enables the construction of portable measurement systems suitable for clinical use without specialized infrastructure. A significant challenge in the design of such systems is simultaneous image acquisition in the visible (RGB) and thermal spectra, and their precise spatial co-registration [11]–[13]. RGB and thermal cameras differ in resolution, field of view, focal length, and physical location, introducing both translational offset and perspective distortion [10].

The problem of modal registration in RGB–IR systems has been widely studied. Applied approaches include feature-based methods [14], [15], mutual-information-based methods [16], and geometric transformations, including planar homography and its constrained affine forms [9]. For compact systems with a fixed baseline and constant working distance, a simplified scale-translation registration can be sufficient when the field of view is limited and the registration quality is verified visually.

This paper presents the design and implementation of a portable thermal and visual data acquisition system, with particular emphasis on a practical RGB–LWIR registration procedure using a calibration board with thermal reference points. The system provides the infrastructure for standardized clinical measurements in thermographic wound healing monitoring studies.

II. RELATED WORK

Several portable multimodal imaging systems combining RGB, depth, spectral, and thermal sensors have been proposed for wound assessment and clinical monitoring. Chang *et al.* [11] presented a handheld multimodal sensor system for pressure-ulcer assessment, integrating RGB-D, thermal, multispectral, and chemical sensing with online wound documentation. Gutierrez *et al.* [12] proposed a mobile workflow for multiview RGB and thermal wound monitoring, mapping

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thermal information onto 3D wound models reconstructed from mobile-device images. These works confirm the value of multimodal acquisition, but they rely on more complex acquisition or reconstruction pipelines than a single handheld RGB–LWIR module intended for rapid bedside measurements.

Thermal-visible image registration remains a separate technical challenge because texture and contrast differ strongly between modalities. Classical feature-based methods such as SIFT and SURF can fail when corresponding local features are sparse or poorly repeatable across spectral bands. Debaque *et al.* [13] studied thermal-visible registration using a homography model and showed that projective correction is a practical formulation for small-baseline thermal-visible alignment. In the present system, the correspondence problem is simplified by introducing physical calibration targets visible in both modalities. The implemented registration uses a constrained affine scale-translation model, which is easier to deploy in a clinical workflow than feature matching during acquisition.

From the clinical side, Liu *et al.* [1] and Kesztyus *et al.* [2] provide comprehensive reviews of thermographic wound monitoring, consistently identifying two key barriers to clinical adoption: the lack of standardized acquisition protocols and the absence of portable, self-contained devices that can be operated by non-expert medical personnel. Ring and Ammer [4] discussed standardization requirements for medical thermal imaging, emphasizing controlled working distance and reproducible geometry as prerequisites for quantitative temperature analysis.

The system presented in this paper addresses the identified gaps through three design decisions that are not commonly combined in prior work: (1) a dedicated dual-visible-IR calibration board that resolves the cross-modal feature correspondence problem without offline processing; (2) an ultrasonic distance sensor that supports a fixed working distance at the hardware level; and (3) a fully self-contained 3D-printed handheld enclosure powered by a battery, enabling bedside use without ancillary equipment.

III. MATERIALS AND METHODS

A. Data Acquisition System

A portable device was designed and constructed to enable simultaneous image acquisition in the visible light spectrum and far infrared (LWIR). The system architecture is shown schematically in Fig. 1.

The control unit is a **Raspberry Pi 5** minicomputer equipped with a quad-core Cortex-A76 processor clocked at 2.4 GHz and 8 GB of RAM [18]. The Raspberry Pi 5 manages the entire data acquisition process: camera initialization, live preview display, image triggering and saving, and export of temperature data to a CSV file. The user interface is based on a touchscreen panel, enabling direct system operation without an external computer.

Visible-spectrum images are captured by the **Raspberry Pi Camera Module 3**, featuring a Sony IMX708 sensor with 11.9 Mpx resolution (4608×2592 px) and phase-detection autofocus [19]. The camera is connected to the computer via a CSI-2 interface.

Thermal images are acquired by the **FLIR Lepton 3.5**, based on an uncooled microbolometer (LWIR, 8–14 μm) with a resolution of 160×120 px [20]. The sensor thermal sensitivity is below 50 mK (NETD). Communication with the minicomputer is via an SPI/I²C interface through the PureThermal 2 module, which acts as a USB bridge and enables readout of both raw thermometric data (in centi-Kelvin units) and video streams in YCbCr format. A full comparison of both cameras’ technical parameters is presented in Table I, while the complete hardware specification of the device is summarised in Table II.

TABLE I. Technical parameter comparison of cameras [19], [20]

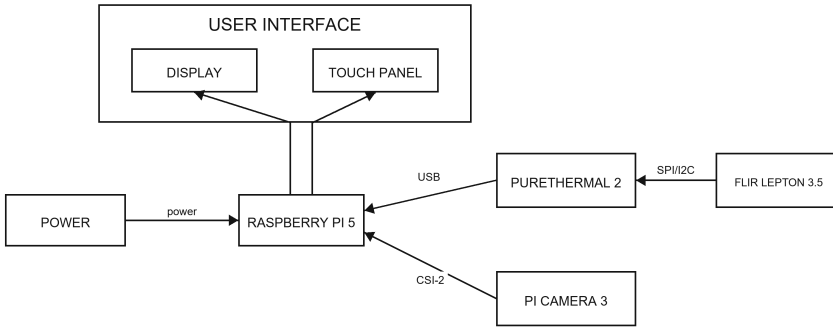
Parameter	Pi Camera 3 (RGB)	FLIR Lepton 3.5 (LWIR)
Sensor type	Sony IMX708 (CMOS)	Uncooled microbolometer
Spectral range	Visible light	8–14 μm (LWIR)
Resolution	4608 × 2592 (11.9 Mpx)	160 × 120
Pixel size	1.4 × 1.4 μm	12 μm
Focal length	4.74 mm	1.77 mm
Horizontal FoV	66°	57°
Diagonal FoV	~ 75°	71°
Focus	Phase autofocus	Fixed
Frame rate	up to 1080p60	8.6 Hz
Sensitivity (NETD)	–	< 50 mK
Interface	CSI-2	SPI / I ² C

TABLE II. Key hardware specifications of the acquisition device

Component	Specification
Enclosure	FDM 3D-printed PLA, 142 × 103 × 73 mm
Control unit	Raspberry Pi 5, Cortex-A76 2.4 GHz, 8 GB RAM
RGB camera	Pi Camera Module 3, 11.9 Mpx (Sony IMX708)
Thermal camera	FLIR Lepton 3.5, 160 × 120 px, LWIR
IR bridge	PureThermal 2 (USB, SPI/I ² C)
Distance sensor	Qwiic Ultrasonic TCT40, I ² C
Working distance	220 mm (fixed)
Illumination	White LED ring
Battery	Samsung 18650, 3500 mAh Li-ion
User interface	Touchscreen, Python/tkinter GUI
Operating system	Raspberry Pi OS (Debian)

Both cameras are mounted in the measurement module housing with a fixed mechanical separation of several millimetres. This configuration ensures stability of mutual optical positioning and repeatability of geometric calibration between measurement sessions, provided that measurements are performed from a constant distance.

1) *Mechanical Enclosure*: The device enclosure was designed using CAD software and manufactured entirely by fused-deposition modelling (FDM) 3D printing using PLA filament. The overall dimensions of the assembled housing are 142 × 103 × 73 mm (length × width × height), resulting in a compact, single-hand-held form factor. The enclosure integrates dedicated recesses for the Raspberry Pi 5 board, the PureThermal 2 module, the battery, the LED ring, and the touchscreen panel, with the two camera apertures positioned at the front face with a fixed inter-camera spacing. All internal



(a) Block diagram of the system



(b) Measurement module

Fig. 1. Data acquisition system: block diagram and view of the measurement module.

components are retained by snap-fit clips and M3 screws, ensuring that the relative positions of the cameras and distance sensor remain unchanged between measurement sessions. The use of 3D printing allows rapid iteration of the mechanical design and straightforward field replacement of individual parts if damaged.

2) *Power Supply*: For patient and operator safety in the hospital environment, the system is powered exclusively by a rechargeable lithium-ion cell. A single Samsung 18650 cell with a nominal capacity of 3500 mAh is used, providing sufficient energy for a full clinical session without the need for mains connection. The cell is housed in a dedicated compartment accessible from the rear face of the enclosure, enabling quick replacement between sessions. A protection circuit module (PCM) provides over-current, over-voltage, and short-circuit protection.

3) *Illumination*: A ring of white LEDs is integrated at the front face of the enclosure, coaxially with the RGB camera aperture. The ring illumination provides uniform, diffuse lighting of the wound surface, reducing the influence of ambient lighting variability on the colour image quality. This is particularly important in clinical rooms where ceiling lights may cast directional shadows that would compromise the visual wound boundary used for ROI definition.

4) *Distance Sensor*: Reproducible working distance is enforced by a **Qwiic Ultrasonic Distance Sensor** based on the TCT40 ultrasonic transducer pair. The sensor operates by emitting a 40 kHz ultrasonic pulse and measuring the time of flight of the reflected echo, converting it to distance. It communicates with the Raspberry Pi 5 over the I²C bus using the SparkFun Qwiic connector system, eliminating soldering and reducing assembly errors. The sensor is mounted on the front face of the enclosure between the two camera apertures.

The working distance for all measurements was fixed at $d = 220$ mm, chosen as a compromise between the field of view of the FLIR Lepton 3.5 (which must fully cover the wound area) and the spatial resolution of the RGB image at that distance. The software continuously reads the sensor

output and displays a real-time distance indicator on the touchscreen; an audible and visual alert is issued when the measured distance falls within ± 5 mm of the nominal value, at which point the operator may trigger image acquisition. This hardware enforcement of working distance is critical because a change in distance causes the two cameras to scale their images at different rates (due to their different focal lengths and sensor sizes), which would invalidate the stored registration parameters and introduce a systematic error in the ROI-to-thermogram mapping.

5) *Software and User Interface*: The acquisition software is written entirely in Python 3 and runs on Raspberry Pi OS (Debian-based). The graphical user interface (GUI) is implemented using the `tkinter` library, providing a full-screen touchscreen-optimised interface without the need for a mouse or keyboard. The `libcamera` stack and its Python bindings (`picamera2`) are used for RGB frame acquisition; thermal frames are retrieved from the PureThermal 2 module via the `pyuvic` library over USB.

The typical operator workflow consists of three sequential steps:

- 1) **Setup and calibration.** At the start of a measurement series the operator positions the device at the nominal distance from the calibration board (confirmed by the distance sensor indicator) and runs the one-time RGB–LWIR registration procedure described in Section III-B. The resulting transformation parameters are stored and reused for all subsequent sessions until the camera module is physically disturbed.
- 2) **Image acquisition.** The operator positions the device at the nominal distance from the patient's wound (again confirmed by the sensor), then triggers simultaneous capture of the RGB frame and the thermal frame via a single on-screen button. Both images are time-stamped and saved to the session directory on a microSD card.
- 3) **ROI definition and data export.** The operator indicates the wound boundaries on the RGB image using the touchscreen. The software automatically transforms the

ROI to the thermal image, generates the RING zone, extracts the feature vector, and writes all outputs (images, raw CSV, feature CSV, metadata JSON) to the structured repository directory.

The entire workflow from device power-on to completed data export typically takes less than five minutes per patient visit, making the system practical for routine clinical use.

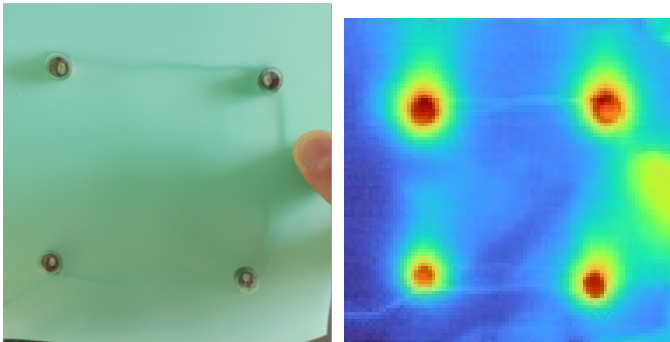
B. Geometric Calibration and RGB–LWIR Registration

1) *Rationale for the Registration Model:* RGB and LWIR cameras differ in spatial resolution, field of view, focal length, and physical location in the measurement module. Consequently, the thermal frame cannot be directly sampled at RGB pixel coordinates. In the present system, the camera module is rigidly mounted and the measurement distance is fixed at $d = 220$ mm using the integrated distance sensor. Under these constraints, the implemented registration model maps the thermal data into the RGB-resolution analysis space using resizing, anisotropic scaling, and translation.

This model can be interpreted as a constrained affine form of a planar projective transformation, in which perspective terms are set to zero. It is therefore less general than a full homography, but it is simple, stable, and consistent with the implemented software pipeline. The registration accuracy is verified visually using thermal-visible overlays before clinical data extraction.

2) *Calibration Board:* A fundamental problem in RGB–LWIR registration is the absence of points naturally visible in both modalities simultaneously. Classical chessboard patterns used in machine vision are thermally neutral and invisible on the LWIR camera. Conversely, thermal objects visible on the IR camera may be blurred or low-contrast in the RGB image.

To solve this problem, a dedicated **calibration board** was designed, consisting of four evenly spaced light bulbs mounted on a neutral background. The bulbs simultaneously emit visible radiation and heat, making them clearly visible both on the RGB image and on the thermogram. The four heated reference points cover the calibration area and provide a direct visual criterion for adjusting and verifying the geometric registration.



(a) RGB image: bulbs visible on the calibration board. (b) Thermogram: bulbs as local temperature maxima.

Fig. 2. Calibration board with four bulb reference points visible in both imaging modalities.

3) *Registration Procedure:* Geometric registration is performed once before a measurement series and proceeds as follows. The auxiliary adjustment tool was implemented in Python using OpenCV 5.0.0. OpenCV is an open-source computer vision library; in the present workflow it was used for image resizing, affine warping, and overlay blending, while the scale and translation parameters were selected by the operator from the calibration overlay rather than estimated automatically by an OpenCV calibration routine [17].

- 1) The device is placed at the fixed working distance from the calibration board, controlled by the distance sensor.
- 2) The raw thermal matrix of 120×160 samples (height $\times$ width, i.e. 160×120 px in image coordinates) is first resized to the RGB frame resolution of 4608×2592 px. This initial operation corresponds to nominal factors of $4608/160 = 28.8$ horizontally and $2592/120 = 21.6$ vertically.
- 3) The resized thermal image is then adjusted using independent horizontal and vertical scale sliders (s_x, s_y) and translation sliders (d_x, d_y). In the calibration tool, 100% on both scale sliders means the already resized 4608×2592 thermal frame; therefore, the reported s_x and s_y are additional correction factors applied after the nominal resize.
- 4) The transformed thermal overlay is compared with the RGB image. The parameters are accepted when the four heated bulbs and board boundaries show satisfactory agreement in both modalities.
- 5) The accepted parameters are stored and applied to the pseudocolour thermogram and to the raw temperature matrix in all subsequent sessions performed with the same camera geometry and working distance.

The use of the same transformation for the visual thermogram and for the raw temperature matrix ensures that the RGB-defined ROI and RING areas are sampled from temperature data in the same aligned coordinate system.

4) *Mathematical Model of the Implemented Transformation:* Let (x_r, y_r) denote a point in the thermal image after initial resizing to the RGB resolution. The implemented registration maps this point to the aligned RGB-resolution analysis space according to:

$$\begin{bmatrix} x_a \\ y_a \\ 1 \end{bmatrix} = \mathbf{T} \begin{bmatrix} x_r \\ y_r \\ 1 \end{bmatrix} = \begin{bmatrix} s_x & 0 & d_x \\ 0 & s_y & d_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r \\ y_r \\ 1 \end{bmatrix}, \quad (1)$$

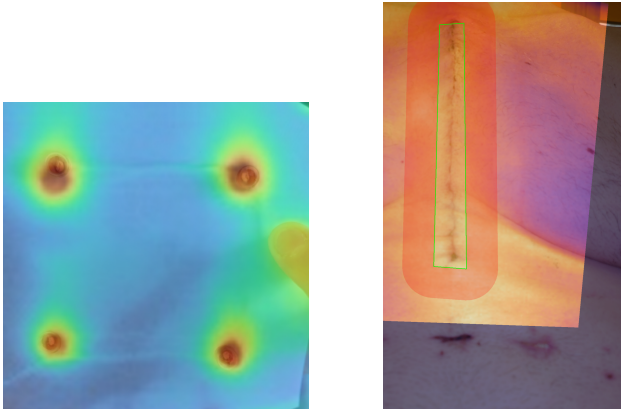
where s_x and s_y are the horizontal and vertical scale factors, and d_x, d_y are translation offsets expressed in RGB-resolution pixels. In the OpenCV implementation, the thermal image is first resized with `cv2.resize`; the accepted scale correction is applied by a second resize operation, and the translation is applied with `cv2.warpAffine` using the 2×3 matrix corresponding to the first two rows of $\mathbf{T}$. The model is a constrained case of a 3×3 projective transformation with $h_{31} = h_{32} = 0$ and $h_{33} = 1$.

For the final analysis script used in the presented workflow, the accepted calibration values were $s_x = 1.05$, $s_y = 0.88$, $d_x = -210$ px, and $d_y = -164$ px. Substitution of these values gives the calibrated scale-translation matrix:

$$\mathbf{T}_{cal} = \begin{bmatrix} 1.05 & 0 & -210 \\ 0 & 0.88 & -164 \\ 0 & 0 & 1 \end{bmatrix}. \quad (2)$$

Direct resizing alone would correspond to $\mathbf{T} = \mathbf{I}$ after the nominal 160×120 to 4608×2592 resize, i.e. $s_x = s_y = 1$ and $d_x = d_y = 0$. The accepted values differ from this identity case: the thermal overlay had to be shifted left by 210 px and upward by 164 px, expanded by 5% in the horizontal direction, and compressed by 12% in the vertical direction. This is why the numerical calibration demonstrates that direct resizing is insufficient for the fixed camera geometry.

a) *Calibration validation:* The correctness of the registration is validated qualitatively by overlaying the transformed thermal image on the RGB image and assessing the agreement of the heated reference points and visible scene structures. Figure 3 shows an overlay validation example and the ROI/RING representation used in the analysis stage.



(a) Cropped RGB-LWIR overlay after scale-translation registration.

(b) ROI and RING zone in the aligned RGB-resolution coordinate system.

Fig. 3. Visual validation of RGB-LWIR registration and ROI/RING definition.

5) *Calibration Validity Conditions:* The determined registration parameters remain valid provided:

- constant working distance between the device and the patient (controlled by the distance sensor),
- no mechanical changes in the camera module (vibrations, impacts),
- approximately repeatable orientation of the handheld module relative to the observed wound area.

In the event of a change in working distance or suspected camera displacement, registration should be repeated. The procedure typically takes less than 2 minutes and can be performed by medical personnel without specialized technical knowledge.

C. Wound Area and Ring Zone Determination (ROI and RING)

Diagnostic data extraction from the image is performed in several stages. First, the operator defines the **region of interest** (ROI) on the RGB image, indicating the wound extent and

width. The ROI is defined as a rectangle inscribed at the wound boundary, oriented along its longitudinal axis.

Subsequently, based on the defined ROI, a **ring area** (RING) is automatically generated after mapping the thermal data into the RGB-aligned analysis space – an elliptical zone around the ROI with a fixed width of 140 px in the aligned RGB-resolution coordinate system. This parameter was selected experimentally as a compromise between:

- avoiding inclusion of background elements (wall, equipment) at excessive width,
- remaining outside the direct thermal influence zone of the wound at insufficient width, which would underestimate the WOUND-RING difference.

The determined ROI contour on the RGB image is used together with the registration transformation $\mathbf{T}$ (equation 1) to sample the corresponding thermal data in the RGB-aligned analysis space. This enables temperature readout from the anatomical area corresponding to the wound visible on the RGB image. The overlay of both areas on the images is presented in Fig. 3.

D. Statistical Feature Extraction

To ensure independence of results from wound length, the defined ROI is divided along its longitudinal axis into 200 evenly spaced points, at which a temperature profile along the wound is interpolated. An analogous profile is determined for the RING area.

From each temperature profile, a set of statistical, geometric, and dynamic features is extracted:

- **Descriptive statistics:** minimum, maximum, mean, median, standard deviation, range.
- **Robust measures:** interquartile range (IQR), median absolute deviation (MAD).
- **Elevated temperature features:** percentiles, energy of the area above the median.
- **Dynamic features:** first and second derivative values of the profile (d_{mean} , d_{std} , dd_{max}) describing the rate of temperature change along the profile.
- **Spatial structure features:** number of gradient sign changes, global linear profile trend, normalized positions of maximum and minimum, centre of mass of the thermal energy distribution.
- **WOUND-RING difference measures:** q_{mean} , q_{std} , q_{max} , RMSE of profile differences, correlation coefficient between the wound and ring profiles.

These features describe both the absolute temperature level and its variability, asymmetry, dynamics of changes along the wound profile, and the thermal relationship between the wound area and surrounding tissue. The complete feature vector contains a total of over 40 variables per measurement session.

E. Data Repository and Clinical Data Management

Data collected during measurement sessions are stored in a structured public repository hosted on GitHub at <https://github.com/LikeInTwo/wound-thermography-dataset>. The adopted

directory structure ensures unambiguous linking of multimodal data with clinical metadata of each patient and session:

```
dataset/
patient_<ID>/
session_<YYYYMMDD_HHMMSS>/
rgb/
<timestamp>.jpg
thermal/
<timestamp>_thermal.jpg
<timestamp>_temp.csv
metadata/
session_info.json
```

Each session directory contains three file types: a full-resolution RGB image (*.jpg), a pseudocolour thermogram (*_thermal.jpg), and a raw temperature matrix (*_temp.csv) stored as 120×160 floating-point values (height $\times$ width) in degrees Celsius. Session metadata are stored in session_info.json with the following fields: patient_id (anonymised numeric code), session_id (timestamp in YYYYMMDD_HHMMSS format), timestamp (ISO 8601), operator (initials), and notes (clinical remarks).

Raw temperature data are stored as a 120×160 matrix (height $\times$ width) of floating-point values in degrees Celsius, computed from camera register values (in centi-Kelvin) according to:

$$T [^\circ\text{C}] = \frac{T_{\text{raw}} [\text{cK}]}{100} - 273.15. \quad (3)$$

The repository is versioned using Git, with large binary files (images, CSV data) stored using the Git LFS (Large File Storage) extension [26]. Patient personal data are not stored in the repository – patient identifiers are anonymous numeric codes. The repository is continuously expanded as new clinical measurement sessions are acquired; therefore, the current number of sessions and unique patients is reported in the repository metadata rather than fixed in the manuscript.

IV. DISCUSSION

A. Hardware Architecture Rationale

The choice of Raspberry Pi 5 as the control unit stems from the availability of camera support tools (libcamera library, Python modules) and the ability to integrate diverse peripherals (CSI-2, SPI, I²C, GPIO interfaces) in one compact, energy-efficient device [18].

The choice of FLIR Lepton 3.5 was motivated by its compact dimensions ($11.8 \times 12.7 \text{ mm}^2$), low power consumption (150 mW), and integration of absolute thermometry (readout in Kelvin) without external processing [20]. Thermal sensitivity below 50 mK is sufficient for detection of clinically relevant temperature differences (differences $\geq 0.5^\circ\text{C}$ reported as diagnostically significant [5]).

B. Significance of Precise Image Registration

The precision of wound area mapping from the RGB image to the thermal image directly affects the quality of extracted diagnostic features. Incorrect pixel assignment (e.g., including background instead of wound tissue) leads to distortion of temperature statistics and, consequently, false-positive or false-negative analysis results.

The performed visual validation (overlay) demonstrated good agreement of the RGB-defined wound ROI and corresponding thermogram areas after scale-translation registration. With the current calibration board, reliability depends mainly on stable geometry, careful manual adjustment, and post-calibration overlay verification. Future versions may include additional thermal-visible fiducial points to estimate a full homography and quantify registration error automatically.

C. Measurement Standardization as a Comparability Condition

One of the main limitations of clinical thermography is the difficulty in achieving repeatable measurement conditions [2], [21]. Factors influencing thermographic results include ambient temperature, air humidity, measurement distance and angle, as well as physical activity and emotional state of the patient [4].

The designed system addresses the standardization problem through:

- an integrated distance sensor ensuring constant working distance between measurement sessions,
- fixed camera module geometry (elimination of mounting errors),
- a single RGB–LWIR registration valid for the entire measurement series,
- LED illumination ensuring stable conditions for the RGB camera.

This approach aligns with recommendations of thermographic societies regarding standardization of clinical image acquisition [21].

V. CONCLUSION

This paper has presented the design and implementation of a portable system for simultaneous RGB and thermal image acquisition, intended for monitoring postoperative wound healing. A key element of the system is the geometric registration procedure that maps thermal data into the RGB-resolution analysis space, based on a dedicated calibration board with four bulb reference points simultaneously visible in both modalities.

The determined scale-translation registration enables consistent mapping of the wound area from the RGB image to aligned thermal data, allowing extraction of statistical and dynamic features from a precisely defined anatomical region. The integrated distance sensor and fixed camera module geometry ensure measurement repeatability necessary for standardized clinical research.

The described system provides a solid infrastructure for further research into quantitative thermographic analysis in the

context of wound healing. In subsequent stages, plans include collection of an expanded clinical database, development of automatic wound area segmentation methods, and clinical validation of extrapolated diagnostic indicators on a larger patient group.

REFERENCES

- [1] Q. Liu, M. Li, W. Wang, S. Jin, H. Piao, Y. Jiang, N. Li, H. Yao, "Infrared Thermography in Clinical Practice: A Literature Review," *European Journal of Medical Research*, vol. 30, no. 1, p. 33, 2025. <https://doi.org/10.1186/s40001-025-02278-z>
- [2] D. Kesztyüs, S. Brucher, C. Wilson, T. Kesztyüs, "Use of Infrared Thermography in Medical Diagnosis, Screening, and Disease Monitoring: A Scoping Review," *Medicina*, vol. 59, no. 12, p. 2139, 2023. <https://doi.org/10.3390/medicina59122139>
- [3] D. G. Armstrong, L. A. Lavery, "Skin Temperature Monitoring Reduces the Risk for Diabetic Foot Ulceration," *American Journal of Medicine*, 2007. <https://doi.org/10.1016/j.amjmed.2007.06.028>
- [4] E. F. J. Ring, K. Ammer, "Infrared Thermal Imaging in Medicine," *Physiological Measurement*, vol. 33, no. 3, pp. R33–R46, 2012. <https://doi.org/10.1088/0967-3334/33/3/R33>
- [5] M. Fierheller, R. G. Sibbald, "A Clinical Investigation into the Relationship Between Increased Periwound Skin Temperature and Local Wound Infection in Patients with Chronic Leg Ulcers," *Advances in Skin and Wound Care*, vol. 23, no. 8, pp. 369–379, 2010. <https://doi.org/10.1097/01.ASW.0000383197.28192.98>
- [6] G. Nakagami, H. Sanada, S. Iizaka, T. Kadono, T. Higashino, C. Koyanagi, T. Haga, "Predicting Delayed Pressure Ulcer Healing Using Thermography: A Prospective Cohort Study," *Journal of Wound Care*, vol. 19, no. 11, pp. 465–472, 2010. <https://doi.org/10.12968/jowc.2010.19.11.79695>
- [7] S. van Netten *et al.*, "Infrared Thermal Imaging for Automated Detection of Diabetic Foot Complications," *Journal of Diabetes Science and Technology*, vol. 7, no. 5, pp. 1122–1129, 2013. <https://doi.org/10.1177/193229681300700504>
- [8] M. Vollmer, K. P. Möllmann, *Infrared Thermal Imaging: Fundamentals, Research and Applications*, 2nd ed. Weinheim: Wiley-VCH, 2017.
- [9] R. Hartley, A. Zisserman, *Multiple View Geometry in Computer Vision*, 2nd ed. Cambridge: Cambridge University Press, 2003.
- [10] Z. Zhang, "A Flexible New Technique for Camera Calibration," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 11, pp. 1330–1334, 2000. <https://doi.org/10.1109/34.888718>
- [11] M.-C. Chang *et al.*, "Multimodal Sensor System for Pressure Ulcer Wound Assessment and Care," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 3, pp. 1186–1196, 2018. <https://doi.org/10.1109/TII.2017.2782213>
- [12] E. Gutierrez, B. Castaneda, S. Treuillet, I. Hernandez, "Multimodal and Multiview Wound Monitoring with Mobile Devices," *Photonics*, vol. 8, no. 10, p. 424, 2021. <https://doi.org/10.3390/photonics8100424>
- [13] B. Debaque *et al.*, "Thermal and Visible Image Registration Using Deep Homography," in *Proc. 25th International Conference on Information Fusion (FUSION)*, 2022. <https://doi.org/10.23919/FUSION49751.2022.9841256>
- [14] D. G. Lowe, "Distinctive Image Features from Scale-Invariant Key-points," *International Journal of Computer Vision*, vol. 60, no. 2, pp. 91–110, 2004. <https://doi.org/10.1023/B:VISI.0000029664.99615.94>
- [15] H. Bay, T. Tuytelaars, L. Van Gool, "SURF: Speeded Up Robust Information," in *Proc. European Conference on Computer Vision (ECCV)*, 2006, pp. 404–417. https://doi.org/10.1007/11744023_32
- [16] P. Viola, W. M. Wells III, "Alignment by Maximization of Mutual Information," *International Journal of Computer Vision*, vol. 24, no. 2, pp. 137–154, 1997. <https://doi.org/10.1023/A:1007958904918>
- [17] OpenCV, "Geometric Image Transformations," OpenCV Documentation. https://docs.opencv.org/4.x/da/d54/group_imgproc_transform.html, accessed 2026.
- [18] Raspberry Pi Ltd., "Raspberry Pi 5 Product Brief," <https://www.raspberrypi.com/products/raspberry-pi-5/>, accessed 2025.
- [19] Raspberry Pi Ltd., "Raspberry Pi Camera Module 3 Documentation," <https://www.raspberrypi.com/documentation/accessories/camera.html>, accessed 2025.
- [20] FLIR Systems, "Lepton 3.5 Longwave Infrared (LWIR) Datasheet," <https://www.flir.eu/products/lepton/>, accessed 2025.
- [21] International Academy of Clinical Thermology (IACT), "Standards and Protocols in Clinical Thermographic Imaging," <https://www.iact-org.org>, accessed 2025.
- [22] R. Gade, T. B. Moeslund, "Thermal Cameras and Applications: A Survey," *Machine Vision and Applications*, vol. 25, no. 1, pp. 245–262, 2014. <https://doi.org/10.1007/s00138-013-0570-5>
- [23] B. B. Lahiri, S. Bagavathiappan, T. Jayakumar, J. Philip, "Medical Applications of Infrared Thermography: A Review," *Infrared Physics and Technology*, vol. 55, no. 4, pp. 221–235, 2012. <https://doi.org/10.1016/j.infrared.2012.03.007>
- [24] S. Bagavathiappan, B. B. Lahiri, T. Saravanan, J. Philip, T. Jayakumar, "Infrared Thermography for Condition Monitoring – A Review," *Infrared Physics and Technology*, vol. 60, pp. 35–55, 2013. <https://doi.org/10.1016/j.infrared.2013.03.006>
- [25] A. Chanmugam *et al.*, "Relative Temperature Maximum in Wound Infection and Inflammation as Compared with a Control Subject Using Long-Wave Infrared Thermography," *Advances in Skin and Wound Care*, vol. 30, no. 9, pp. 406–414, 2017. <https://doi.org/10.1097/01.ASW.0000522161.13573.62>
- [26] GitHub Inc., "Git Large File Storage (Git LFS) Documentation," <https://git-lfs.com>, accessed 2025.