Supporting Thermal Imaging for Activity and Health recognition by a constant temperature device

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Figure 1. Contactless vital data assessment by thermal images.

Abstract

The contactless detection of vital parameters in humans and animals is crucial for ensuring health. While sensors that touch the body or are invasive can already accurately capture parameters such as body temperature, heart rate, or respiratory rate, contactless systems are still under development. An interesting technological approach involves the use of thermal cameras for capturing vital data, as they can operate unobtrusively even in complete darkness and from a greater distance. Unfortunately, the section of measurements affects the recorded temperature; the absolute temperature is imprecise, and calibration is very complex and should be redone periodically. This paper presents a simple yet effective solution for enhancing thermal imaging. The solution is a temperature-controlled Peltier element with a feedback loop that provides an exact reference point in the desired temperature range. This might improve the detection of fever and infections and support further vital data recognition in humans and animals or condition monitoring in machines using thermal cameras.

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → *Health informatics.*

iWOAR '24, June 28–29, 2024, Potsdam, Germany

ACM ISBN 978-1-4503-XXXX-X/18/06.
https://doi.org/10.1145/xxxx

Keywords: thermal camera, non contact, vital data recognition, condition monitoring

ACM Reference Format:
Gerald Bieber, Erik Endlicher, Christopher Wald, Peter Gross, and Bastian Kubsch. 2024. Supporting Thermal Imaging for Activity and Health recognition by a constant temperature device. In *iWOAR '24: International Workshop on sensor-based Activity Recognition and Artificial Intelligence (iWOAR), June 28–29, 2024, Potsdam, Germany*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/xxxx

1 Introduction

In recent years, technological advancements have paved the way for novel approaches to physiological monitoring, and thermal cameras have emerged as a promising tool in this domain. Unlike conventional methods, thermal cameras offer a non-contact and non-intrusive means of capturing physiological data, making them an attractive option for inflammation, fever, or continuous heart rate monitoring.

Furthermore, the integration of thermal cameras in health monitoring systems aligns with the growing trend of wearable and ambient technology. This not only enhances user convenience but also opens avenues for continuous monitoring in various environments, including home settings, workplaces, and even during physical activities. The ubiquitous nature of thermal cameras makes them a versatile tool for capturing physiological signals without disrupting daily routines, offering a new paradigm in personalized healthcare.

Contactless determined vital data represent the health and fitness of humans and animals. Together with other medical data, this data provides information about the need for medication or further medical assistance. Temperature monitoring of the skin and body also helps to detect stress in the workplace and can reduce workload and enable a lifetime of healthy working. Furthermore, the recognition of vital data also makes it possible to improve communication with other people at a distance. Communication is also improved with AI-based machines, as they are better able to assess the inner states of the person they are talking to and can therefore respond to them in particular.

Traditional approaches to vital data detection often involve cumbersome devices, uncomfortable sensors, or invasive procedures, limiting their widespread adoption and compliance among individuals.

The motivation behind exploring through thermal cameras lies in the potential to enhance how we monitor health. This approach could provide a seamless and unobtrusive method for individuals to track the health in real-time, facilitating early detection of anomalies and enabling timely intervention.

Even the resolution of thermal cameras and the relatively accuracy between each pixel might be sufficient, the disadvantage is the absolute error of temperature assessment caused by the camera and the sections of measurement.

In this paper, we delve into the exploration of vital data detection using thermal cameras, aiming to bridge the gap between thermal camera technology and health monitoring. By presenting a calibration device that is easy to build and use, we show that a reference temperature spot beside the region of interest can be applied. This calibration device is mobile and allows an eays estimation of the absolute temperature of the object.

1.1 Physical Concept

All objects with a temperature above absolute zero (-273.15°C) emit infrared radiation. The intensity and wavelength of this radiation depend on the object's temperature. This leads to the Stefan-Boltzmann Law that describes the total power radiated per unit surface area of a black body (an idealized object that absorbs all incident electromagnetic radiation) as a function of its temperature.

$$P = \sigma \cdot A \cdot T^4$$

P is the total power radiated,

σ is the Stefan-Boltzmann constant $(5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}})$,

A is the surface area of the object, and

T is the absolute temperature of the object in kelvin.

This law implies that as the temperature of an object increases, the amount of infrared radiation it emits also increases significantly. Interestingly, as the temperature of an object increases, the peak wavelength of its emitted radiation decreases. This means that hotter objects emit radiation with shorter wavelengths, while cooler objects emit radiation with longer wavelengths. The Wien's Displacement Law is representing this as:

$$\lambda_{\max} \cdot T = \text{constant}$$

where: - $\lambda_{\max}$ is the peak wavelength of radiation, - T is the absolute temperature of the object.

This law indicates that the peak wavelength ($\lambda_{\max}$) of the emitted radiation from a black body is inversely proportional to its absolute temperature (T). As the temperature (T) increases, the peak wavelength of the emitted radiation decreases. Prisms refract electromagnetic waves and split them according to their wavelength. An array of photosensitive sensors can detect the intensity of the different rays and generate an overall image. This principle is fundamental to the operation of thermal cameras, as they capture and interpret these infrared emissions to create thermal images, allowing us to visualize temperature variations across surfaces and objects.

1.2 Application fields

Thermal cameras find applications in various fields due to their ability to capture infrared radiation and visualize temperature differences. Relevant applications can be found in the fields of physical and chemical reactions, agriculture, welding processes, building insulation, etc. Some notable applications include medical applications. Here, thermal cameras are used to detect inflammation, assess blood flow and monitor body temperature. They are also used in thermography to detect breast cancer. In addition, a thermal body scan can detect Covid infections [1]. Since thermal imaging cameras have become cheaper, they have become attractive for many purposes.

2 Related Work

Most thermal cameras in the market are calibrated and set to factory standards. However, over time, the calibration drifts due to the aging of the electronic components. Furthermore, the measuring section often varies. The measured temperature differs because of the surrounding temperature, moisture, distance between object and camera and of course by the quality of the camera. The general calibration method is described in [8]. For an accurate calibration, a controlled environment with an almost ideal black body is applied. All achieved data is used to create a measurement model tailored to each camera's unique lens, filter, and temperature range [10]. High quality thermal cameras come along with a calibration certificate and it is recommended to recalibrate the camera each year. The accuracy of black bodies is usally in the range of 0.1-0.3 C. Other methods for calibration provide a trade of between effort, price and quality [15]. A rough calibration method is to use egde points like cold or boing water (0 or 100 degree) but the surface of water is heart to measure. Unfortunately, the relationship between temperature and infrared energy is nonlinear, and a reference point close to the temperature region of interest is needed.

The camera based technologies are using the visible skin and body surface for heart beat detection. Hereby, the RGB camera is sensing the chromatic changes of the skin color that occur every heat beat. This technology, which is also used by the CareCam [7] in the working environment by standard webcams, is known as remote plethyphotogrammetry (rPPG). Thermal imaging cameras, on the other hand, use the temperature differences in the skin that occur during the heartbeat. But not only heart rate is relevant, 2 shows the blood flow in a cow's skin and illustrates the position of the arteries and vessels.

2.1 Sensor Technology

Distance
Most IR-based fever thermometers only measure within half a meter. However, thermal imaging cameras can have an unlimited range (and are even used in remote sensing from

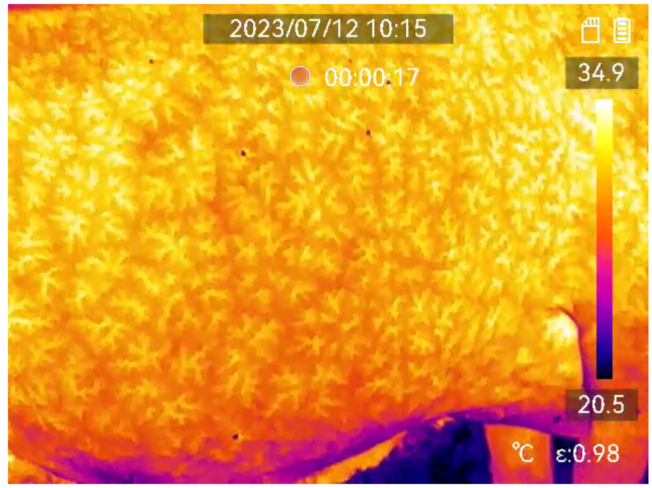

Figure 2. The high resolution shows the blood flow of a cow, which can be recognized as a star pattern (by Mirjam Lechner).

satellites), but their accuracy is affected by the sequences of measurements. Cooled thermal cameras (e.g. used by police) may detect persons in a distance of 15 km [6].

Resolution
Due to the different areas of application, there are single-point and sensor arrays. Infrared (IR) thermometers, also used and known as ear thermometer, forehead, or temporal artery thermometers, usually consist of an infrared sensor to measure the temperature of the skin surface. Sensor arrays range from simple 8X8 sensor arrays (e.g. grid-eye [14]) to high-performance and high-resolution sensors (e.g. HD thermal videos). Plug-in modules for smartphones are usually available with ¼ of the VGA resolution.

NETD
But the resolution is not the single parameter from interest. The quantization, or thermal sensitivity, describes the smallest temperature difference that a camera can detect. This sensitivity is referred to as Noise Equivalent Temperature Difference (NETD), units are Kelvins (mK). The lower the number, the more sensitive the detector [17]. Obvisously, thermal camera sensors consist of temperature sensitive semi conductors. As every semi conductors, the electrical circuit suffers on thermal noise. Therefore, high performance thermal camera are cooled to reduce the thermal noise. These type of cameras are extremely cost extensive and mainly used in area of research.

Absolute Temperature
While NETD describes the relative error between the pixel values, the absolute temperature error indicates how well the value corresponds to the actual temperature. The thermal

imaging camera measures the thermal radiation of an object, so the emitted radiation can vary due to different surface properties. A shiny, golden surface reflects the thermal radiation in such a way that sometimes the temperature of other reflected objects is measured. For some materials that are transparent, such as a person's glasses, the thermal radiation is blocked and the eye/eye temperature cannot be measured. Furthermore, the angle of the view of sight is influencing the obtained temperature [16], the distance in the air [11], the presence of wind [3], and the influence of sunlight. This leads to a total thermal error, depending on the thermal camera device, of approx. 3 degree C [13].

2.1.1 Body Temperature.

Determining the core body temperature with a thermal camera is always an indirect method and therefore prone to error. The result is influenced by various factors, as only the surface temperature is measured and this value is used to determine the core body temperature. The conversion of the surface temperature into the core body temperature is influenced by various factors such as the ambient temperature, physical activity and individual fluctuations. It is likely that the areas with the best blood flow are the most suitable for temperature estimation [9]. Interestingly, in farm animals the regions around the eyes (e.g. cows, 3) and in humans the forehead are particularly suitable. Since the absolute temperature accuracy of thermal imaging cameras from a distance may not be very precise, fever detection can be performed during group observations to identify outliers with a significantly higher temperature than the standard objects.

Figure 3. Thermal image of a cow.

2.1.2 Further vital data recognition.

Respiration detection

With a thermal imaging camera, it is possible to indirectly detect and measure a person's respiration by recognizing temperature differences based on the body's heat radiation. When a person exhales, warmer air escapes from the respiratory tract, leading to a temperature difference compared to the surrounding environment [2]. Therefore, a low absolute temperature error is not necessary if a high NETD is provided.

Heart Rate detection

A thermal camera can indirectly estimate the heart rate by detecting subtle changes in the blood flow and variations in body temperature. When the heart pumps blood, it distributes warm blood throughout the body. Each heart beat, the skin and other body areas are supplied by the blood that is enriched with oxygen, heat, nutrients and other ingredients. By monitoring specific regions of interest on the face or other exposed body parts, a normal webcamera can track volume or color variations over time [7]. Temperature variations also provide patterns that can be analyzed to estimate the heart rate indirectly. The temperature differences are very tiny and require a high resolution with a low noise recording [5]. It is obvious that a heart rate detection can be determined by thermal cameras. In [12], a good overview is given about the current works and technologies in that field. In [4], the authors were using a 640 x 480 pixel camera with NETD = 30 mK and stated that heart rate and heart rate variability detection is possible and valid.

3 Challenges on thermal imaging

The literature analysis shows that although thermal imaging cameras are good at depicting the temperature difference within an image, the absolute temperature determination can sometimes be very faulty. This is due to the ability to measure the absolute temperature as well as the influences of the measuring distance, humidity, air speed and other influencing parameters. Furthermore, shiny surfaces may interfere the measurements. Hereby, reflections are possible that lead to inaccurate readings. Resolution, distance to the object and the angle between object surface and camera may also influence the received results. It would therefore be desirable if a reference signal with a known temperature were available in the field of view of a thermal image. This reference signal could be provided by a device that has a constant temperature that is independent of the environment.

Shiny Surfaces: Reflections from shiny or reflective surfaces can lead to inaccurate readings. The emitted thermal radiation may bounce off these surfaces, causing false temperature measurements.

Resolution: Achieving high-resolution thermal images can be challenging. Super-resolution techniques, often based on deep learning, are used to convert low-resolution thermal images into higher-resolution counterparts1.

4 Constant temperature device

The aim was to design a simple, easy-to-use but accurate device that would provide the desired reference temperature when taking a thermal image. The core of this device is a Peltier element, which cools one side of the element and heats the other by means of current flow. If the heat on one side is dissipated, for example with a cooling plate, the other side of the Peltier element can assume the desired temperature. If a thermometer is attached to the Peltier element with a thermal paste, the desired temperature can be set and achieved using a relay and a control circuit.

Figure 4. First prototype of the temperature reference device.

If the desired temperature is not yet reached, the Peltier element is heated; if the temperature is exceeded, the Peltier element is cooled. The arrangement (4) therefore corresponded to a three-point controller (cool, heat, leave in state).

5 Implementation and Setup

For the purpose of a constant temperature device, we choose the following hardware elements. An arduino uno as the digital control circuit, a Peltier element (TEC1-12706, 15 V 6.4 A 65 W (L x B x H) 40 x 40 x 3.8 mm), a resistor of 6 Ohm to limit the intake current, a relay (Debo SRD-05VDC-SL-C 2 Channel, 10 A) to switch the current or reverse the current direction, a heat sink (Kalolary Aluminium Heatsink 40 * 40 * 20 mm) and a thermometer (BMP280, DS18B20) attached directly to the Peltier element with conductive paste.

6 Evaluation of designed system

The prototype was used at a test set for the temperature measurement of cows. The camera was approx. 4 meters away to the object, but the temperature reference device was directly close to the object (see figure 5). Within the field of view of the thermal camera, both the object and the reference device was clearly visible.

Figure 5. First prototype of the temperature reference device.

6.0.1 Results. The surface temperature of the designed reference device was set to 25 degree C. The temperature of the reference system fluctuated around the set value, so that the mean value was achieved exactly, but a standard deviation of 0.05 degrees could be measured. he measurement results showed that no overshooting occurred and that the control loop was stable. The camera images displayed almost the set temperature of the reference system without calibration; the determined offset was then transferred to all pixels. For the tests, we also used a thermal camera with a resolution of 640x480 px. The width of the field of view was 1.2m that represents 5 px per centimeter. The used reference surface of the peltier element had the size of 4 x 4 cm, therefore the reference-surface was recorded with 400 px. This amount of pixel was sufficient for our calibration procedure. Furthermore, the reference devices needed some time to reach it´s reference temperature. In 6, the calibration time was approx. one minute, depending on the environment temperature and the required reference temperature. The time delay can be easily changed in the set up by other resistors and power supply.

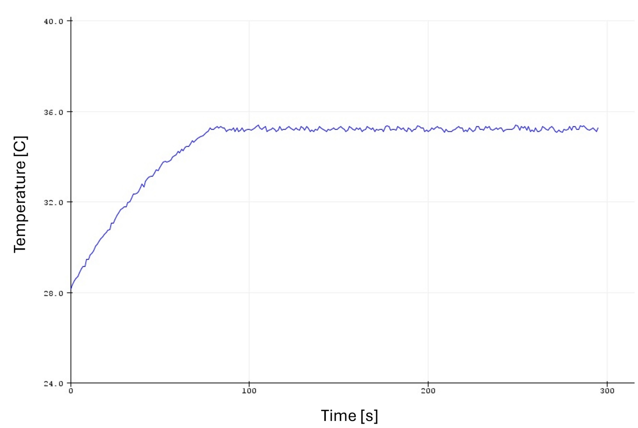

Figure 6. First prototype of the temperature reference device.

7 Discussion

The evaluation showed that a reference temperature is supporting a reliable and accurate measurement. On the other side, the introduced reference system is only used and designed to measure close to the reference temperature. It would be nice to retrieve a full range calibration, but this needs additional efforts and doesn't cover the error of the sections of measurement. Furthermore, we could see that the reference device produced a fluctuating temperature output. This reason is a three point controlling circuit that is currently not optimized. Here, an enhancement can be done in future. The performed evaluation was close of a simple proof-of-concept test. We suggest to perform an extensive evaluation that determines the influences or advantages of various measurement sections, e.g. high humidity, sun reflections etc. With the presented device, even very cheap thermal cameras can provide accurate thermal images and can be used for fever detection or other purposes. Some thermal camera do not provide a radimetric output but only a temperature representation as a gray image. With the know reference temperature, the absolute temperature can be estimated. In the tests, we could figure out, that the physical dimensions of the reference area should fit to the camera resolution. Therefore, a very small reference-area (far distance images) may provide insufficient pixel counts for a reliable reference information. Possible solution might be an optical zoom or bigger reference surfaces. In the application field of vital data analysis of animals, a cow might carry a reference temperature as a tag or within the barn some reference points can be set up easily.

8 Conclusion and Outlook

Thermal imaging cameras impress with their ability to capture important data without contact and in complete darkness. Due to the ambient temperature, humidity and distance to the object being measured, thermal imaging cameras provide inaccurate absolute values. The error is usually in the range of 2 degrees Celsius and is not sufficient for many absolute measurement requirements. In this paper, we present a reference temperature system that is easy to build, easy to set up and inexpensive and allows the improvement of the measurement of body temperatures, fever, infections, etc. by absolute values. This system consists of a Peltier element that can maintain a constant, predetermined temperature through a control loop. This reference system is held in the field of view of the camera so that the absolute deviation can be determined and calculated. We estimate that our concept of temperature difference can also be used as an ear tag for cows and for various measurements to determine animal health. In addition, very inexpensive thermosensor arrays can be improved as reference systems, so that widespread monitoring seems plausible in the future. Further work will focus on the 3D propagation of thermal radiation to gain a broader understanding of the applicability of thermography.

Acknowledgments

This work was funded by the Fraunhofer Innovation Grant Program, Germany, and the Federal Ministry of Economic Affairs and Climate Action.

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