Development of Radiant Warmer Thermal Monitoring System to Improve Neonatal Patient Safety
Yenidoğan Hasta Güvenliğini Artırmak Amacıyla Radyant Isıtıcı Termal İzleme Sistemi Geliştirilmesi

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***Abstract*—Temperature measurement is a vital part of daily newborn care. In temperature measurement, accurate measurements must be taken to detect deviations from expected values for the incubator and radiant heater function. Monitoring the temperature is keeping the baby in a thermoneutral environmental zone. The study tested body surface temperature under various clinical conditions using an affordable infrared thermography imaging technique. Temperature distributions are displayed as real-time videos and analyzed to evaluate average skin temperatures. This study demonstrates the design and implementation of a virtual temperature sensing application that can help neonatologists provide additional security to a newborn's skin temperature. The influence of different environmental conditions inside the radiant heater with respect to the surface temperature has been verified.**

Keywords—radiant warmer; neonatal; neonatology; intensive care

***Özetçe*—Sıcaklık ölçümü, günlük yenidoğan bakımının hayati bir parçasıdır. Sıcaklık ölçümünde, inkübatör ve radyant ısıtıcı işlevi için beklenen değerlerden sapmaları tespit etmek amacıyla doğru ölçümlerin alınması gerekmektedir. Sıcaklığı izlemek, bebeği termonötr bir çevre bölgesinde tutmaktır. Çalışmada uygun fiyatlı kızılötesi termografi görüntüleme tekniği kullanılarak vücut yüzey sıcaklığı çeşitli klinik koşullar altında test edilmiştir. Sıcaklık dağılımları gerçek zamanlı video olarak görüntülenmesi sağlanmakta ve ortalama cilt sıcaklıklarını değerlendirmek amacıyla analiz edilmektedir. Bu çalışma, neonatologlara bir yenidoğanın cilt sıcaklığına ek güvenlik sağlamaya yardımcı olabilecek sanal bir sıcaklık algılama uygulamasının tasarımını ve uygulamasını göstermektedir. Yüzey sıcaklığı ile ilgili olarak radyant ısıtıcının içindeki farklı çevresel koşulların etkisi doğrulanmıştır.**

Anahtar Kelimeler—radyan ısıtıcı; yenidoğan; neonatoloji; yoğun bakım

I. INTRODUCTION

A radiant heater is used in newborn care facilities to keep a small or premature baby at the desired temperature [1]. Radiant heating devices have a heating element, a device body, two skin probes placed on the body, and a control system. The heating element; emits heat energy to provide warmth to a baby. The skin probe measures the baby's skin temperature, and the control system adjusts the heater element according to the measured skin temperature [2]–[4]. In order to maintain the body temperature of newborns, it is aimed to minimize the energy spent in metabolic heat production with incubators and radiant heaters. Devices with these system features, which have different characteristics but common purposes, are commercially available [5].

The control system usually regulates the heat energy provided by these devices to keep the skin temperature constant with the help of the probe attached to the newborn's abdomen. The most significant advantage of the radiant heater is that it provides easy access to critically ill babies without disturbing the thermal environment. The major disadvantage is the increase in the imperceptible water loss produced by the radiant heater. Systems in existing devices usually adjust/monitor temperature monitoring and control based on temperature data received from one or more regions [7].

In using a conventional neonatal warmer, there are some technical problems in regulating the neonatal temperature. In existing radiant heater systems, since newborn body temperature measurement is taken from certain parts of the body with sensors, temperature data is based on data/information from that part only. However, when the newborn body is considered whole, temperature data cannot be obtained from those regions in cases where hyperthermia or hypothermia occurs in some areas. As a result, body temperature data obtained from newborns may vary (and vice versa), and such a problem may affect the entire system.

Specifically, a skin-mounted temperature sensor only measures temperature from a small body part, but skin temperature can vary with different parts of the baby's body. This sensor may become dislodged, creating a risk of overheating or underheating. In particular, a traditional radiant heater may have trouble making sense of data from a partially displaced or slowly detaching sensor over time that measures ambient and skin temperatures. In this case, hypothermia and/or hyperthermia states may be experienced in parts of the newborn's body that the sensor cannot measure.

In most existing systems, when it detects that the newborn's body has lost heat, it helps to warm the newborn's body by adjusting the power of the radiant heater module on the system with the control system. While doing this, it can only do this with the data taken from the probes placed in certain parts of the body. However, in some cases, this is not enough. For example, some parts of the newborn's body overheat, while others do not increase linearly. Or, in case of an existing infection, some parts of the body overheat.

Also in existing systems, there are alarm systems in universal standards against the complications of hyperthermia and/or hypothermia that may occur due to overheating of the newborn. However, these alarm systems use existing system data. If the data coming from the system is not meaningful under ideal conditions, the heater algorithm does not work correctly.

In order to prevent hyperthermia or hypothermia complications in newborns, real-time monitoring of all parts of the body should be provided. To achieve this, infrared thermography (IRT) sensors with optical sensor technology must scan the whole body. In this way, a two-dimensional image can be created by compiling data from almost every part of the body. In the research, no integrated structure using this technology was detected in any known existing devices.

To examine regional differences in temperatures, we investigated the utility of infrared thermography as a noninvasive method for measuring body temperature in premature infants. This exploratory methodology was used to visually and quantitatively examine the differential temperatures seen between central and peripheral skin temperatures in our previous studies. Infrared thermal imaging offers a non-contact way to measure temperature and may offer the potential for use to detect changes in temperature in hospitalized premature infants. There are limited reports of the use of infrared thermal imaging in extremely premature infants in heated incubators [8], and this manuscript reports our experience with this methodology.

II. Materials & Methods

All objects having a temperature above absolute zero emit electromagnetic radiation called thermal radiation [7]. The temperature of an object determines the spectral emission. The electromagnetic spectrum is divided into wavelength regions, which are distinguished by the methods used to produce and detect radiation within each band. These regions are called X-ray, ultraviolet (UV), visible, infrared, microwave, and radiowave bands. The wavelength regions of most importance for biologic imaging are the visible (400–700 nm), near infrared (700 nm–1 mm), midwave infrared (2–5 mm), and longwave infrared (8–12 mm). Infrared thermography records the temperature distribution of a surface using infrared radiation emitted by that body within the 0.8 mm–1.0 mm band [9].

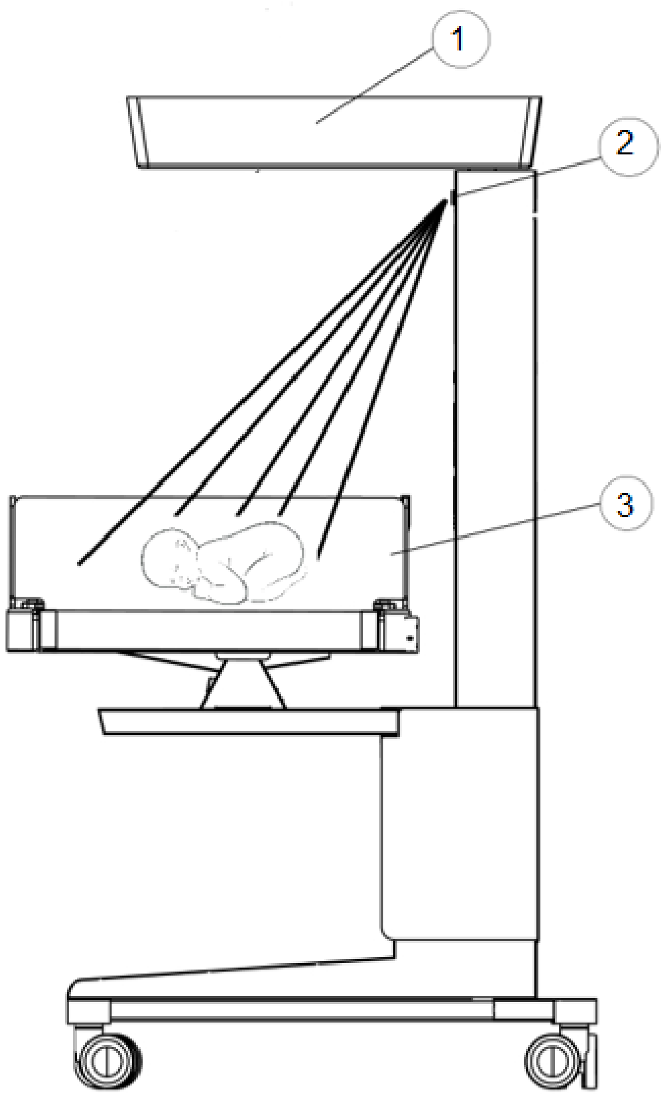

Figure 1: The thermal imaging sensor placement; (1) radiant warmer heater head, (2) thermal imaging sensor placement, (3) neonatal patient bed.

To record an image of an object, an infrared camera captures thermal radiation using a detector and records the amount of emitted thermal radiation at each spatial position. The amount of radiation the camera is able to measure depends on the temperature and emissivity of the object. Emissivity is a measure of how much radiation is released from an object relative to an object with no reflectivity (ability to reflect radiation) at the same temperature. Human skin exhibits an emissivity of 0.97–0.98 in the wavelength range of 2–14 mm [10]. It is determined that there is no difference in emissivity between black, white, or burnt skin when measured in vivo or in vitro [10]. An infrared camera measures and records an image called a thermogram, which comprises the emitted infrared radiation from an object's surface displayed as pixels arranged in a two-dimensional array. In Fig. 1, the thermal imaging sensor placement on the device is expressed.

Melexis MLX90640 Far infrared thermal sensor array (32x24 Pixel Resolution) is used for thermal imaging. The sensor has advantages such as low cost, high level of precision and superior noise performance. The sensor contains total 768 pixels. An ambient sensor is integrated to measure the ambient temperature of the chip and supply sensor to measure. Pixels in the whole of view (FOV) can be seen in Fig. 2.

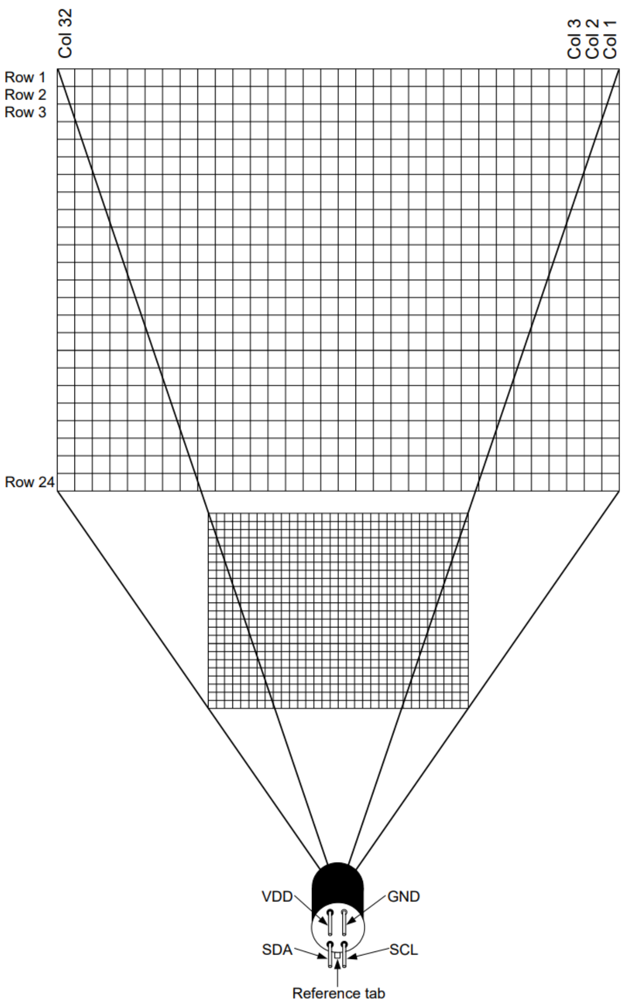

Figure 2: Pixel in the whole Field of View [6].

A. Thermal Imaging Technique

The control card consists of microcontroller, high resolution Analog-to-Digital Converter (ADC), system information display, motion sensor, buzzer, connection connectors, data transfer interface and power control circuit components [11]–[13]. The microcontroller in the control card enables to convert the data received from the thermal sensor and the temperature data of the baby placed in the bed into a visual consisting of 32x24 pixels. These pixels makes images that show a distribution of the heat values gathered by the temperature sensors. With these thermal images, the comparation will be placed and the temperature probes that are separated from the baby or that do not measure correctly will be detected. The audible warning on the control card compares the temperature data obtained from the probes with the thermal sensor data and gives a warning when the difference exceeds a preset error value. The equation calculates the error value as follows equation 1.

When the error value exceeds the predetermined value, the user will be warned. Here, not the instantaneous state of the difference, but the time-dependent saturation filling rate will be considered.

$$y = e(x) + [(T_{IRT} - T_{probe}) \cdot t] \tag{1}$$

where e is error value, T_{IRT} is IRT temperature of body center, T_{probe} is calculated probe temperature value, t is time.

The screen provides the display of the two-dimensional image created by the microcontroller in the control card. The screen provides the display of temperature information at different points of the baby, which is created by the microcontroller in the control card. The error function could be used while checking temperature sensor and camera values.

A thermal monitoring system is a system that ensures that a patient receives the optimum warming benefit from a radiant heater. This is achieved by creating a visual of whether the patient is in the optimal warming zone. It creates an additional security system in case of incorrect reading of temperature data obtained from probes built into the body. Technically, it does this with a sensor that displays a two-dimensional image on the device's screen. In the system, the temperature information of the baby's probe-mounted areas is obtained with the probes attached to certain points of the baby in the bed heated by the radiant heater. The temperature information of the baby's whole body is detected by the thermal sensor. The temperature information is converted into two-dimensional visuals by the control card and presented to the user on the screen. The temperature information coming from the probes and the thermal sensor is compared by the microcontroller in the control card. When the difference between the temperature data obtained from the compared probes and the thermal sensor data exceeds a preset error value, a warning is given by the audible warning on the control card.

B. Test Setup

The Incu II Neonatal Warmer Tester device was used for detection of different temperature value from different bed placement. The device is an all-in-one Incubator/radiant neonatal warmer analyzer that simplifies testing and ensures proper performance and safety of infant incubators, transport incubators and radiant neonatal warmers. The test procedure can be seen in Fig.3.

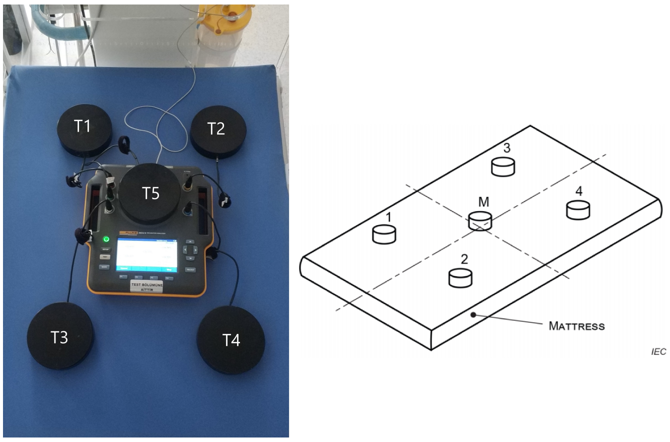

Figure 3: Test setup. Sensor pucks(T1-T5) placement is placed as in IEC 60601-2-21 standard

The data got from the Incu II device was brought from the device via USB communication with the PC. Data was previously structured with comma-separated values (CSV) by the device. The data was used for making the graphs for comparison purposes.

III. Results and Discussion

In summary, the results obtained from the thermal sensor demonstrate its ability to accurately track different geometric profiles over the external anatomy on the mean values. To further advance the use of the thermal sensor in neonatology, we used embedded contactless temperature monitoring in a neonatal radiant warmer. This approach can reduce the need for skin temperature electrodes and not only the problems associated with their use, such as sensor dislocation, motion artifacts, calibration drift, wire crowding, false connections, and the possibility of infection in newborn infants, but also for safety purposes while follow-up the temperature electrodes doing their job right.

In Fig. 4, the grahp shows the measurement results from different devices. In the graph, temperature T5 is the measurement of center prob of the device, camera is the what the thermal sensor reads themperatures, and the skin probe is the temperature of the device's electrode placed at the T5. From the graph, it can understand that the T5 and skin probe correlate with each other. At the same time, the mean temperature of T1, T2, T3, T4, and T5 is statistically similar to the temperature of the thermal sensor ('camera') detected temperature.

Lastly, the neonatal mannequin is used for temperature measurement from the temperature sensor. In Fig. 5, it can be seen different measurement placements on the radiant warmer

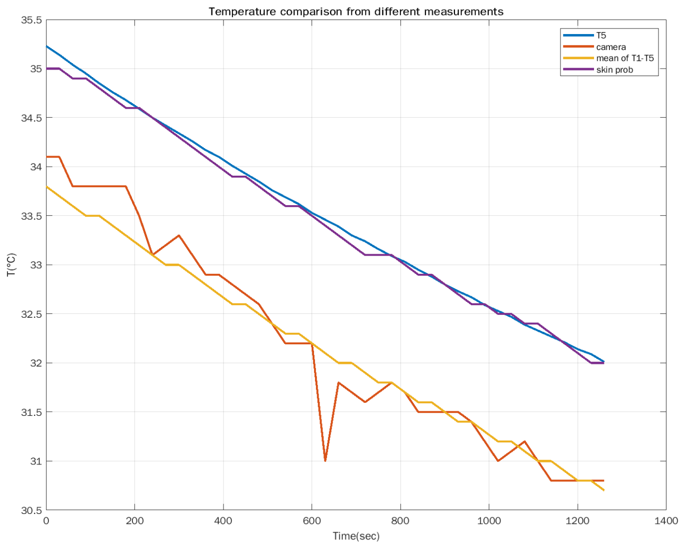

Figure 4: Temperature comparison from different measurements

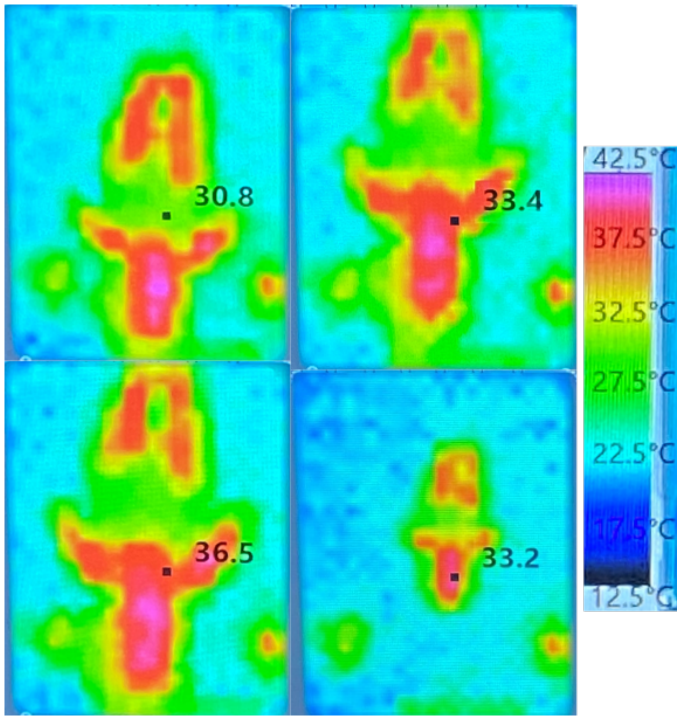

Figure 5: Bitmap of the thermally imaged baby mannequin

display. It can help to detect the temperature distribution of the newborn while displaying on the device screen. The touch screen gives the opportunity to get temperature values from the touched size on the screen. With this, it is possible to detect body temperature in real-time. This technique is much more suitable and cost-effective in comparison to thermal cameras [14].

IV. Conclusions

Using a non-invasive technique to determine the energy expenditure of premature infants provides a significant benefit due to the delicate nature of infants. It has the practical advantage of being able to monitor rapid changes in body temperature, allowing analysis of how it affects infant physiology during certain clinical procedures, such as portable X-ray imaging. Furthermore, these applications can be a part of widespread adoption, and the use of computing vision technologies is opening new and innovative ways to improve neonatal healthcare.

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The authors declare that they have no conflict of interest.

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