A COMPARATIVE ANALYSIS OF THERMOPILE SENSORS FOR BIOMEDICAL APPLICATIONS

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Abstract

This paper presents a comparative analysis which integrates the field of view (FOV) characteristics of several sensors currently popular on the market. We use thermopile-type thermal sensors which detect the infrared radiations from the human body and then convert them to signal. In order for the temperature to be calculated correctly, in-depth knowledge of the sensor characteristics is necessary. This allows the creation of suitable systems for various biomedical applications such as diseases detection, controlling of physiotherapy processes, etc.

1. INTRODUCTION

Measurement of temperature has been of interest to mankind since antiquity. The beginning of modern understanding of temperature measurement is considered the end of the 16th century. Then Galileo, the first temperature-measuring device, was created based on the idea of expanding and shrinking gases. An important step in the development of temperature measurement methods is the introduction of the first temperature scale by Fahrenheit in the early 18th century. In the middle of the 18th century, Celsius offers a decimal temperature scale. In the early 19th century, Lord Kelvin offers a universal absolute thermodynamic temperature scale that has become the standard in today's temperature measurement [1].

The reasons for the tremendous interest in measuring temperature develop in several major lines.

To ensure high-performance industry, one of the measured quantities characterizing the processes and condition of the equipment is the temperature. This is an important feature of almost every production process that determines the variety of methods and tools used [2].

One of the most important factors for determining a person's health is their body temperature [3-6]. Body temperature is a magnitude characteristic of the degree of heat that is determined by the internal kinetic energy of the thermal movement of the molecules. Therefore, temperature can be regarded as a conditional statistical magnitude, proportional to the average kinetic energy of body molecules [3].

Therefore, it is extremely important to know what the measured temperature depends on, in what limits it varies. Of course, the methods of measurement are varied. In order to accurately measure temperature in a particular setting, it is necessary to properly build its corresponding measurement system, taking into account all (as far as possible) influencing factors.

This paper examines a small part of the temperature measurement techniques used in diagnostic and therapeutic systems [7-10].

The use of non-contact sensors also increases due to the ban on the use of mercury thermometers in the countries of the European Union.

2. THEORETICAL BACKGROUND

It is well known that the temperature measurement methods are divided into two basic groups: contact and non-contact. In contact methods, the exchange of energy between the medium and the thermometer is based on thermal conductivity, and on non-contact – heat radiation.

There are three basic physical principles used in temperature measurements [1]:

I. Determination of the temperature by measuring some of the physical characteristics depending on it; 2. By measuring some temperature-dependent physical characteristics of thermometric bodies placed in the environment and receiving their temperature by heat exchange; 3. Measurement of heat radiation of heated bodies. This method is used to measure the temperature of the different surfaces.

Here we will mainly concentrate on the third method [8-10]. Clearly, the final results should be comparable and usable with previous research by other authors. That is why we will use the international temperature scale (ITS). It is a practical realization of the theoretical thermodynamic scale adopted in the middle of the 20th century with the most accurate approximation. The thermodynamic scale starts from absolute zero. It coincides with the scale of a gas thermometer filled with ideal gas that is calibrated at the triple point of the water [1].

ITS has undergone several adjustments and uses multiple reference points that are reproducible with high enough accuracy.

The interpolation between the reference points of the temperature scale is calculated on the basis of formulas illustrating the ratio of temperature to standard thermometer readings. Various thermometers are used in different areas of the temperature scale.

The practical application of the thermopile for non-contact temperature measurement is increased. This is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel [2, 9, 11-13].

Ideally the output from the thermocouple pair will be a voltage that is directly proportional to the temperature difference across the thermal resistance layer and also to the heat flux through the thermal resistance layer. Adding more thermocouple pairs in series and making a thermopile increases the magnitude of the voltage output. The output of a thermopile is usually in the range of tens or hundreds of millivolts [9].

3. GENERAL SET-UP

We will take a look at the basic ideas for using thermopile sensors for biomedical purposes. Naturally, we start with the idea of static observation of the object.

It is important to note that we will assume that we are considering the simplest form of energy transfer between the object and the sensor. That is, the energy spreads in the so-called viewing angle. This approximation is possible due to the relatively small distances between the object and the sensor. They are in the order of centimeters.

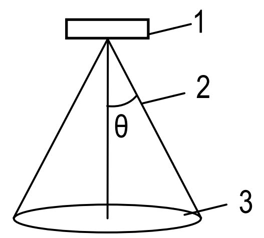


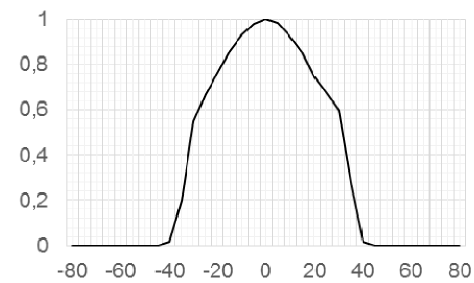
Figure 1. General set-up for observation (1-sensor, 2-FOV, 3-sensed area)

For this reason, we do not use additional optical elements and we do not calculate MTF [14].

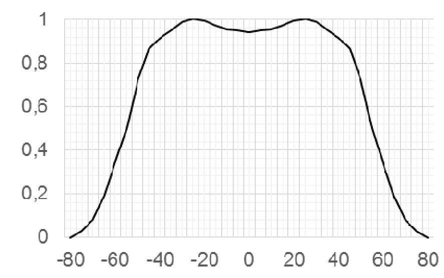
However, we note that in the viewing angle the distribution is not uniform. This distribution is given by many manufacturers in the relevant company documentation. Here we will look at data from four such sensors.

In the following figures (Fig.2 – a,b,c,d), we present the dependence of the normalized voltage received by the sensor on the angle of the four different sensors available on the market at the moment. We use sensors as follows – a-TP339, b-TS318, c-TMP007, d-MLX90616 [15-18].

In order to effectively use these catalog data, we have processed them as a set of discrete numerical values U(θ).



a



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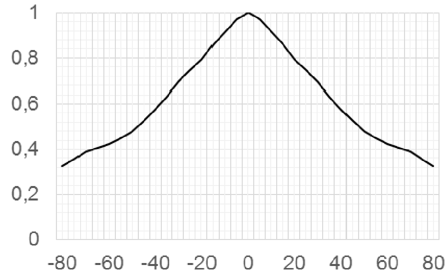

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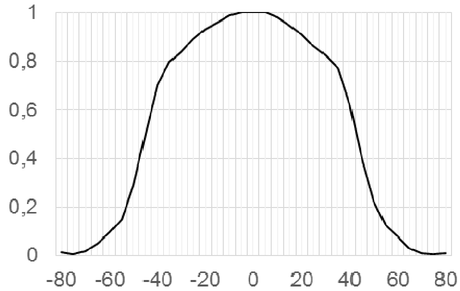

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Figure 2. Approximated data for FOV for different sensors, x axis is the angle θ in degrees, and the axis is the normalised output. The sensors are a-TP339, b-TS318, c-TMP007, d-MLX90616

The difference in the viewing angle is essential if we try to receive 2-dimensional results based on the xy sensor movement. Then, in a non-flat object, it is necessary to consider the distance between position 1 and 3 in Fig.1 [19]. Such scenarios can be used with the simultaneous application of physiotherapy and temperature control. Of course, two-dimensional imaging can be used with a multi-point sensor and a suitable optic. In this case we have no possibility to add a second distance correction sensor. The main issues with single sensor systems are lower data acquisition speed (compared to array) and problems of a mechanical nature.

4. NUMERICAL EXPERIMENTS

Again, we will look at the layout of Figure 1. We use the classical approach for deriving solid angle with integration of unit surface element in spherical coordinates [19]

$$\Omega = \int_0^{2\pi} \int_0^{\theta} \sin\theta' \, d\theta' \, d\varphi \, . \qquad (1)$$

After integration we derive

$$\Omega = 2\pi(1 - \cos\theta) \, . \qquad (2)$$

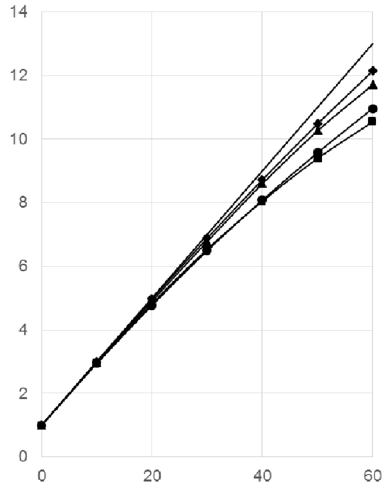
It should be noted that the observed area presented on Fig.1 as pos.3 is relatively small.

We now calculate the normalized integral energy for the four sensors in question. We use the data from the guidelines by integrating (2) numerically for different angles

$$\int_{\theta_1}^{\theta_2} U(\theta) \, d\theta \qquad (3)$$

As a point of focus, the relationship between integration for the different sensors and an idealized sensor without angular dependence is of interest.

The results are presented graphically in Figures 3-a and 3-b.



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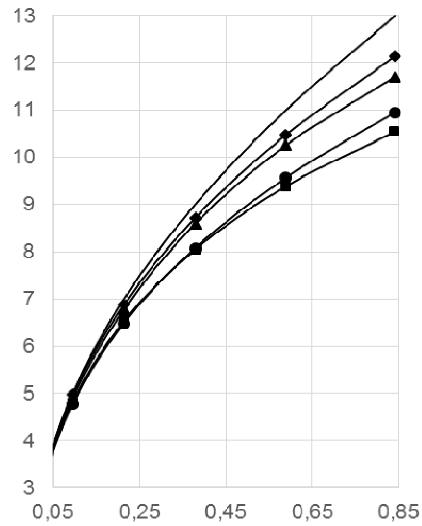

b

Figure 3. Results from numerical integration, a – x axis is the angle θ in degrees, b – x axis is the solid angle Ω in steradians (lines without marks – ideal sensor; curves with diamond marks – MLX90616; curves with triangle marks – TS318; curves with circle marks – TMP007; curves with square marks – TP339;)

5. CONCLUSION

When measuring body temperature in areas with a shape other than the plane, it makes sense to adjust the data from infrared sensors. Nowadays, this can be achieved relatively cheaply with mechanical scanning and addition of a second distance sensor. The work may have biomedical applications, such as skin temperature control in hand-held laser therapy and more.

6. ACKNOWLEDGMENTS

We would like to thank the Scientific Research Sector of TU-Sofia for the financial support.

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