Correction of temperature estimated from a low-cost handheld infrared camera for clinical monitoring

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Abstract. The use of low-cost cameras for medical applications has its advantages as it enables affordable and remote evaluations of health problems; however, the accuracy is a limiting factor to use them. Previous studies indicate that parameters from object position like distance camera-object and angle of view could be used to improve temperature estimation from thermal cameras. Nevertheless, most studies are focused on expensive thermal cameras with good accuracy. In this study, an innovative experimental setup is used to study the errors associated to temperature estimation from a low-cost infrared camera: FlirOne Gen3. In our experiments, the image acquisition is done from multiple point of view (distance camera-object and viewing angles) and by using a thermal camera manipulated by hand. Then, using a regression model, a correction is proposed and tested. The results show that our proposed correction improves the temperature estimation and enhance the thermal accuracy.

Keywords: Temperature Correction, Low-Cost Infrared Cameras, Clinical Thermal Imaging.

1 Introduction

Thermographic has the potential as a noninvasive tool to be used in clinical monitoring as shown in some studies: [1-5]. However, accurate estimation of the temperature is sometimes required for using it in clinical settings. Professional infrared cameras have the highest accuracy (around +/-1°C) but they are expensive and hard to manipulate.

In recent years, there have been improvements in IR imaging with portable and low-cost cameras as they are more convenient to be used for remote clinical monitoring [6, 7]. On the other hand, the disadvantage of low-cost cameras is the large errors. Technical specification of low-cost IR cameras like FlirOne Gen3 show accuracy of +/-3°C or +/-5%.

Some studies show the possibility to improve temperatures estimation from thermal cameras and recent ones consider low-cost cameras. Curran and al. proposed a correction by using a reference object with known temperature in the field of view of the thermal camera [8]. The proposed correction worked well for various thermal cameras but no significant improvement was found for a low-cost IR camera like FlirOne.

It is known that the accuracy depends on many factors, including the distance of the object, the ambient temperature and the emissivity of the observed material. Theoretical studies [9, 10] and experimental results on human skin [11, 12] indicate that the emissivity decreases significantly when the viewing angle is greater than 60°, i.e. the angle between the optical axis of the camera and the normal to the surface, which leads to inaccurate temperature mapping.

Therefore, some works proposed correction for directional emissivity. Cheng and al. estimated a linear relationship from the calibration of the measurement error due to the viewing angle [13]. Zeise and Wagner used a non-linear least squares optimization minimizing the error of the measured output signals from theoretical models describing emissivity as a function of the viewing angle for known material emissivity class (metal/dielectric) [14]. Arnon and al. proposed a correction for clinical monitoring by thermal images based an empirical second-degree polynomial equation for calibrating the decreasing apparent temperature due to dependency of the skin emissivity on the viewing angle [15]. All the previous methods were tested and used with high end thermal cameras but not with low-cost IR cameras.

The distance between the camera and the object has also been considered. Ting and al. uses a Kinect to obtain information on the depth of the image scene and proposed a correction based on it [16]. The correction was tested and accuracy was improved in a low-resolution thermal camera.

In the case of a handheld camera, the shooting protocol cannot be perfectly normalized and the point of view remains approximate. In this paper, we present an experimental setup using only a low-cost camera held in hand to study the variations of thermal measurements induced by the camera point of view. Then, we propose a correction based on a regression model to correct the temperature as a function of the viewing angle and the distance of the camera to object.

The document is organized as follows: Section 2 shows the experimental setup; Section 3 shows the analysis of absolute errors using a low-cost IR camera; Section 4 proposes a methodology for correction; and Section 5 shows the results after implementing the proposed correction.

2 Experimental Setup

The low-resolution camera used for the experiments is FlirOne Gen 3 (Flir Systems, Oregon, USA) which according to the specifications has accuracy +/-3°C or +/-5%, thermal resolution 80x60 and thermal sensitivity is 150mK.

To analyze the errors, an experimental setup where the temperature could be measured and controlled is required. This is achieved by using a temperature-controlled stage and a controller with LCD touchscreen from LINKAM (Linkam Scientific Instruments Ltd, Waterfield, Epsom, United Kingdom). The temperature stage has a circular piece of metal in the middle which has 2 cm of diameter. The temperature could be set to any value between -196°C and 125°C; and the circular piece of metal will increase its temperature until reaching the desired degrees with an accuracy of less than +/-0.1°C.

Once the temperature is achieved, the device keeps it for around one hour. The metal piece had a reflective surface which was covered with carbon tape for eliminating reflections.

Additionally, four Aruco Markers are placed around the object of interest (piece of metal) to estimate the camera pose relative to the object. From the pose, we principally consider the distance of the camera from the object and the angle between the optical axis and the normal of the object surface. A label is placed on the side of the device to easily identify the set temperature in the experiments. The experimental setup is shown in Fig 1.

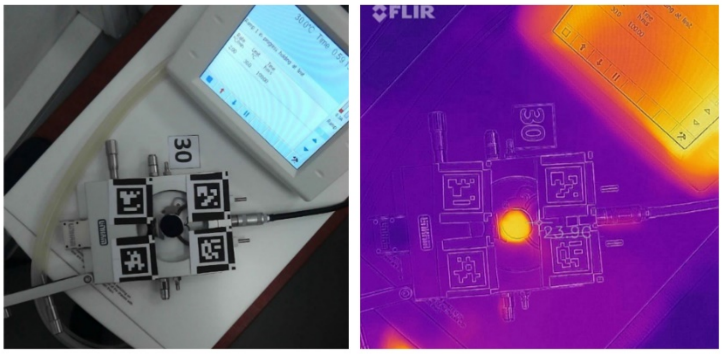

Fig. 1. Experimental set-up.

Using this experimental setup, 365 thermal images were captures with FlirOne Gen3 camera connected to an iPad and holding them by hands, varying the point of view for a temperature scale from 20 to 40 degrees Celsius. The distance of the camera from the object was varied from 13 to 70 cm and the angle from 0 to 60 degrees. Some examples of image shooting are illustrated in Fig 2 while Fig 3 shows different camera poses.

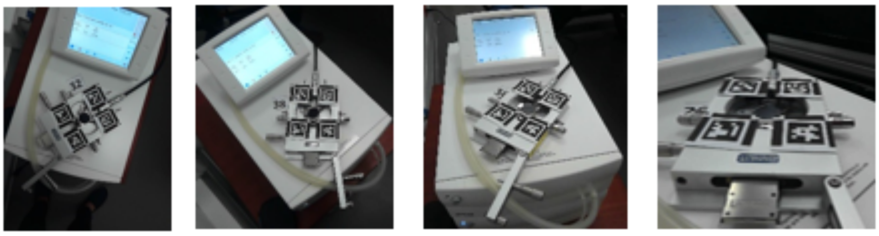

Fig. 2. Sample of images of the temperature stage using FlirOne Gen3. a) shows the RGB image and b) shows the mixed image (RGB and Infrared image).

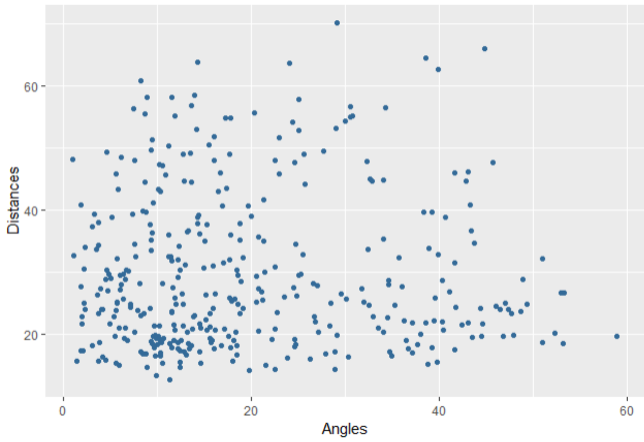

Fig. 3. Different camera poses (distances and viewing angles) for image acquisition.

The temperature has been measured in thermal images using a free package called "thermimage" within statistical software R based on the standard equations used in thermography and described in [17]. The estimation obtained is similar to the one used in commercial Flir software: Thermacam Researcher Pro. Massard and al. shows that the difference between the estimations from commercial Flir software and the free implementation has mean 0.03°C and a standard deviation of 0.0312°C [17].

The temperature estimation takes into account several parameters from the thermal camera which are named Plank constants. The only parameters that have been customized are the following: emissivity, ambient temperature and distance camera-object. For all images, the emissivity was specified to 0.98; ambient temperature to 22°C; and the distance in centimeters was estimated from the four Aruco markers.

The temperature of the metal plate is measured in the thermal image by the median value in a region of interest (ROI) of 6x6 pixels (T_{Est}).

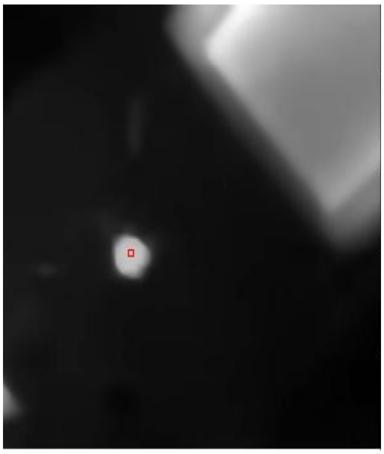

Fig. 4. Thermal image and the ROI of 6x6 pixels used to estimate the temperature of metal plate.

3 Analysis of errors

The difference between the reference temperature (T_{Ref}) and the temperature estimation (T_{Est}) are used to calculate the estimation errors. Fig 5. Shows the boxplots of the absolute error at different reference temperatures. The graph suggests a relationship between the absolute error and the reference temperature.

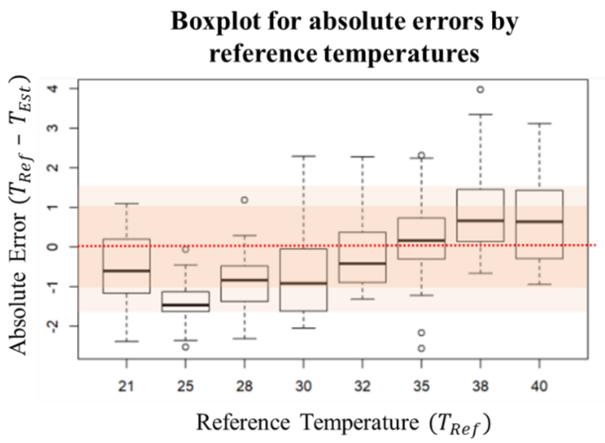

Fig. 5. Boxplot of absolute errors at different reference temperatures.

Similarly, to study the errors regarding the camera position, some plots of the absolute error against the distance and angles are shown in Fig 6. On the right, the scatterplot shows the relationship between the estimation errors and the distance from object to the camera. It could be seen a relationship with the distance. On the other hand, the left image shows the errors plotted against the angles. In this case, a weaker linear relationship with the angles is observed.

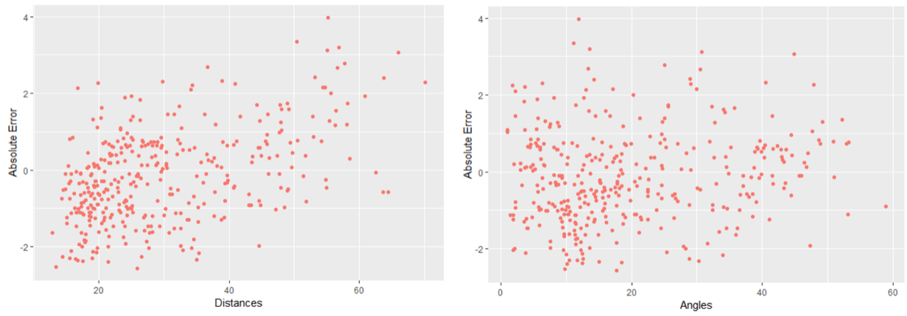

Fig. 6. Scatterplots of the estimation errors against the distances from camera to object (left) and angle between camera plane and object plane (right)

Based on the relationship observed between the error and the point of view (distance and angle), it seems possible to propose a correction of the measured temperature.

4 Proposed model for correction

As we want to use the correction for clinical purposes, the dataset used for the proposed correction is filtered to temperatures from 30 to 40 degrees; distances between 10 and 50 cm; and angles between 0 to 40 degrees. A set of 190 images were finally selected.

A regression model is proposed to correct the estimated temperature. This model will be used to estimate reference temperature; however, T_{Ref} will not be used as the response variable. This variable is controlled in the experiments and therefore is not a random variable that could be fitted using regression model. Instead, T_{Est} is used as the response variable and inverse prediction is used for estimating T_{Ref} using the regression model.

Different polynomial models were tested using distance, angle in simple and quadratic forms. The models were fitted using 70% of the data collected leaving 30% of the data for testing the model. The selection of the final model was done based on adjusted squared R-Squared and its structure is presented in eq (1). The estimated coefficients (β_i) are given in Table 1.

$$T_{Est} = \beta_0 + \beta_1 T_{Ref}^2 + \beta_2 D^2 + \beta_3 A + \beta_4 A^2 + \varepsilon \qquad (1)$$

Table 1. Estimated beta coefficients for model described in Eq. (1)

Predictors	Estimates	Confidence Interval	p-value
Intercept (β_0)	19.84312	[19.04801 – 20.63824]	<0.001
RealTempQuad (β_1)	0.01244	[0.01185 – 0.01303]	<0.001
DistanceQuad (β_2)	-0.00069	[-0.00091 – -0.00046]	<0.001
Angle (β_3)	0.04821	[0.00046 – 0.09595]	0.05
AngleQuad (β_4)	-0.0012	[-0.00235 – -0.00004]	0.044
Observations	137		
R2 / adjusted R2	0.930 / 0.927		

In order to implement this model to estimate the reference temperature, a methodology used commonly in chemistry for calibration of instruments is used. This methodology is called inverse prediction ([18]) and it allows to predict the values of the variable of interest: the reference temperature (T_{Ref}).

Finally, when this proposed model is applied to estimate the reference temperature, the results show that the errors are reduced. Fig. 7 shows the boxplots without outliers for the absolute error before and after using the proposed correction and Table 2 shows the statistics associated to the boxplots. Before correction, the errors were between -1.67°C and 2.20°C; and Root Mean Squared Error (RMSE) was 0.863. After applying the proposed correction, the errors are between -1.01°C and 1.29°C; and the RMSE is now 0.756.

Fig. 7. Boxplot of the absolute errors before and after using the proposed correction.

5 Conclusions

Portable and low-cost cameras like FlirOne Gen 3 could have a low accuracy as described in their specifications. In the use of clinical applications with handheld camera, the point of view cannot be controlled carefully.

The temperature accuracy depends on point of view and in particular, on the distance of the object and viewing angle. This study shows that it is possible to improve the temperature estimation by using a regression model and inverse prediction. As a result, this could enable improvements in low-cost infrared cameras for being used in clinical measurements.

Future work includes using corrected thermal information and combine it to 3D models of wounds for creating a monitoring system. For doing this, the correction proposed based on camera pose will be used and tested in thermal images from human skin. The correction is expected to remain similar even if there are changes in the material and emissivity of the object measured.

Additionally, the model proposed could be refined if more data is collected at a larger set of temperatures; for example, if experiments are done at each temperate degree between 30°C and 40°C.

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