Are the IR cameras FLIR ONE suitable for clinical applications?

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SUMMARY

BACKGROUND: Infrared Thermography (IRT) has been used in clinical environments for at least six decades. In 2014 affordable and attractive low-cost infrared cameras were introduced into the market that facilitated the ability of being attached to mobile devices such as tablets and smartphones. Despite these cameras do not satisfy the minimum specifications recommended for clinical use they have already been used in clinical applications. It is therefore important to verify the performance of these devices. In this paper the start-up stability and the absolute temperature offset, in particular within the temperature range of the human body, are evaluated using the android and iOS OEM connection versions of the FLIR ONE IR 2nd generation and compared from the end user point of view.

MATERIALS AND METHODS: Four FLIR ONE IR 2nd generation cameras were used, two developed to be attached to android systems and the other two to apple iOS systems. A start-up drift test at 30 ºC and a temperature sweep from 20 ºC to 40 ºC in steps of 1 ºC, representing the human body temperature range, were carried out. For the temperature performance assessments, a blackbody Isotech Hyperion R Model 982 was used as temperature reference (uncertainty of ±0.1°C). It was first set at 30ºC temperature reference for the start-up drift test, the cameras along with the attached devices were switched on and measurements were taken at five-minute intervals for one hour at a distance of 30 cm from the blackbody target. For the temperature sweep, the blackbody reference was set to 20ºC. Images were then taken with the IRT imaging devices and readings were taken while the blackbody setpoint was increased in steps of 1ºC up to 40ºC, waiting 15 minutes in between each step for blackbody temperature stability.

RESULTS: The FLIR One 2nd generation thermal cameras overestimate the temperature reading during the start-up offset drift test and take around 15 to 20 minutes to reach measurement stability with an average difference from the blackbody indicated temperature of 0.9 ºC. In the human body temperature offset drift test there is a higher difference from the calibration source at temperatures below 24 ºC, where the temperature readouts are more than 2.0 °C above the real temperatures set at the blackbody. There is a high interclass correlation between the thermal cameras' readings and the calibration source set temperatures and also between the measurements of the two OEM versions of the thermal cameras studied. The span of limits of agreement (LOA) of the measurements of all FLIR ONE 2nd generation cameras with the blackbody temperature was 2.23 ºC.

CONCLUSIONS: Despite these systems being attractive in price and manufacturer provided features, their operational performance does not comply with the required standards for clinical use. The thermal information provided by these imaging systems should only be taken into account for monitoring purposes, as some previous research demonstrated, and not as an input for diagnostic judgments, if they require absolute temperature values to be correct. It is important to note that the cameras provider does not advertise them as medical devices.

KEY WORDS: Affordable IR cameras, FLIR ONE 2nd gen, Infrared thermography, mobile thermography

EIGNEN SICH DIE INFRAROTKAMERAS DER SERIE FLIR ONE FÜR DEN KLINISCHEN EINSATZ?

HINTERGRUND: Die Infrarot-Thermographie (IRT) wird seit sechs Jahrzehnten für klinische Untersuchungen eingesetzt. Im Jahr 2014 wurden erschwingliche und attraktiv kostengünstige Infrarotkameras auf den Markt gebracht, die einfach an mobile Geräte wie Tablets und Smartphones angeschlossen werden können. Obwohl diese Kameras nicht die für den klinischen Einsatz empfohlenen Mindestspezifikationen erfüllen, wurden sie bereits im klinischen Einsatz verwendet. Daher ist es wichtig, die Leistung dieser Geräte zu überprüfen. In diesem Beitrag werden die Anlaufstabilität und für den Temperaturbereich des menschlichen Körpers die absolute Temperaturabweichung der Android- und iOS OEM-Versionen der FLIR ONE Infrarotkameras (IR) der 2. Generation bewertet und aus Sicht der Endanwender verglichen.

MATERIALIEN UND METHODEN: Vier FLIR ONE IR-Kameras der 2. Generation wurden verwendet, von denen zwei entwickelt worden waren, um an Android- Systeme angeschlossen zu werden. und die anderen zwei für Apple iOS-Systeme. Für 30 °C wurde die Anlaufstabilität getestet und der Temperaturbereich des menschlichen Körpers zwischen von 20 °C und 40 °C in Schritten von 1 °C überprüft. Zur Beurteilung der Temperaturerkennung wurde ein Schwarzkörperstrahler Isotech Hyperion R Model 982 als Temperaturreferenz verwendet (Unsicherheit von 0,1°C). Es wurde zunächst eine Referenztemperatur von 30°C für die Untersuchung der Anlaufstabilität gewählt, dann die Kameras zusammen mit den angeschlossenen Geräten eingeschaltet und Messungen im Fünf-Minuten-Takt eine Stunde lang in einem Abstand von 30 cm vom Schwarzkörper durchgeführt. Für die Überprüfung des Temperaturbereichs wurde die Referenztemperatur des Schwarzkörperstrahler auf 20°C gesetzt. Dann wurden mit allen Infrarot-Kameras Bilder aufgenommen und daraus Messwerte ausgelesen. Dieser Vorgang wurde wiederholt, nachdem der Sollwert des Schwarzkörpers in Schritten von 1°C bis 40°C erhöht und zwischen jedem Schritt 15 Minuten auf die Temperaturstabilität des Schwarzkörperstrahlers gewartet worden war.

ERGEBNISSE: Die Wärmebildkameras der 2.Generation von FLIR One überschätzten den Temperaturwert während des Tests der Anlaufstabilität und brauchten etwa 15 bis 20 Minuten, um die Messstabilität mit einer durchschnittlichen Differenz von 0,9 °C zur Referenztemperatur des Schwarzkörpers zu erreichen. Im Abgleich des Temperaturbereichs des menschlichen Körpers fanden sich höhere Unterschiede zur Kalibrierquelle bei Temperaturen unter 24 °C, wobei die Temperaturwerte mehr als 2,0 °C über den realen Temperaturen des Schwarzkörpers lagen. Es zeigte sich eine hohe Korrelation zwischen den Klassen der Messwerte der Wärmebildkameras und den eingestellten Temperaturen an der Kalibrierquelle, aber auch zwischen den Messungen der beiden OEM-Versionen der untersuchten Wärmebildkameras. Die Spanne der Übereinstimmungsgrenzen (LOA) der Messungen aller FLIR ONE Kameras der 2. Generation mit der Schwarzkörper-Temperatur betrug 2,23°C.

FAZIT: Obwohl diese Systeme im Preis und in den vom Hersteller bereitgestellten Funktionen attraktiv sind, entspricht ihre Leistung nicht den erforderlichen Standards für den klinischen Einsatz. Die von diesen Bildgebungssystemen bereitgestellten thermischen Informationen sollten nur zu Überwachungszwecken berücksichtigt werden, wie einige frühere Untersuchungen gezeigt haben, und nicht als Ausgangspunkt für diagnostische Beurteilungen, die für die korrekte Beurteilung absolute Temperaturwerte erfordern. Es muss betont werden, dass der Kameraanbieter die Geräte nicht als Medizinprodukte bezeichnet.

SCHLÜSSELWÖRTER: erschwingliche Infrarot-Kameras, FLIR ONE 2. Generation, Infrarot-Thermographie, Mobiltelephon-Thermographie

Thermology international 2019, 29(3) 95-102

Introduction

Infrared thermography (IRT) imaging has been employed in medical applications for six decades. It is a quick, non-contact, non-ionizing and safe modality for assessing large areas of skin surface temperature distribution. The information provided is associated with the peripheral blood flow which is influenced by the autonomic nervous system among other factors. It has been employed in the physiological study of vascular, sympathetic, musculoskeletal and locomotor systems [1-3].

To increase the accuracy and repeatability of the imaging modality, recommendations were made [3-6] for standardising it in terms of the examination room, the recording equipment and subject preparation, before and during the appointment as well as the image capture protocol. This resulted in a reduction of the variables that influence thermographic assessments while at the same time improving the exchange of knowledge and understanding.

In 2006, Plassmann et al. [7] proposed a set of low cost and simple tests to assess the performance of IR cameras that are used in medicine. Those tests included verification of start-up drift, long-term drift, offset variation over a temperature range, image non-uniformity and the thermal flooding effect.

Three years later, Howell and Smith [8] proposed guidelines for specifying and testing an IR camera for medical applications.

In the ISO standards for fever screening using IRT imaging [9] minimum requirements were specified as a focal plane sensor array size of 160x120, with a NETD of <50mK at 30º C and a measurement uncertainty of ±2% of the overall reading in Celsius (-20 °C to 120 °C).

The first low-cost IR cameras were introduced into the market by manufacturers in 2014 at a very attractive price of around 300.- EUR. The first known assessment of this type of cameras was made by Curran et al. [14]. It concluded that the FLIR ONE does not appear to be suitable for collecting absolute temperature data even when a calibration procedure is employed.

However, Hardwicke et al. [11] demonstrated that using this inexpensive IR system, it was possible to detect and map perforators, define perforasomes, and monitor free flaps. Preoperative, intraoperative, and postoperative obtained thermograms can assist in the planning, execution and monitoring of free flaps, and the FLIR ONE can provide a low-cost adjunct that could be applied to other areas of burns and plastic surgery.

A group of Japanese researchers [12]) suggested that FLIR ONE can work as an alternative device for assessing subclinical inflammation in pressure ulcers and the diabetic foot in clinical settings. Their results may lead to clinicians accepting the proposed method to use thermal imaging assessment at the patients' bedside.

A research letter from Norway [13] raised the issue that absolute temperature estimation may be unreliable with the FLIR ONE camera. However, in perforator mapping, only relative temperature differences are used. Dynamic IRT can increase the reliability of the FLIR ONE for perfusion imaging in the preoperative, intraoperative, and postoperative phases of perforator flap surgery, in line with previous research [11,14].

Sokol et al. [15] observed that a smartphone-based infrared imaging device was capable of detecting thermal trends during sequential zone 1 (Z1) aortic cross clamping as well as zone 3 (Z3) aortic balloon occlusion procedures (resuscitative endovascular balloon occlusion of the aorta [REBOA]) by using an anatomical 2-point thermal ratio. There were also easily recognized qualitative differences between control and occlusion images that allow immediate determination of adequate occlusion of the aorta. This system presented a potentially inexpensive and accurate tool for assessing perfusion, adequate REBOA placement, and even inspecting the level of aortic occlusion.

A group of US researchers [16] demonstrated that using a FLIR ONE camera it was possible to identify that individuals with focal-onset epilepsy have colder abdominal areas.

Jaspers e t al. [17] in the Netherlands showed that the FLIR ONE thermal imager is highly reliable in terms of patient, observer and random error variance. The mean error of measurement in the burn affected area of interest varied between 0.17-0.22°C. However, despite having moderate validity, it has only been tested as an add-on and not as clinical evaluation plus FLIR ONE versus only clinical evaluation. Although, the FLIR ONE is feasible to use, allowing easy and fast measurements of burns in clinical daily practice.

A research group from Washington [18] demonstrated a high degree of accuracy, reliability, and ease of use for assessing limb perfusion with a FLIR ONE camera. It also allowed for rapid and reliable identification of adequate tourniquet placement that was not affected by major haemorrhage or blackout conditions.

A research paper comparing the FLIR ONE 2nd generation for Android with an Android mobile device attached SEEK thermal camera [10] concluded that the FLIR camera outperformed the SEEK but its images were rich in noise.

A recent PhD thesis [20] showed the importance of having the sensors Focal Plane Array (FPA) stabilized to obtain and ensure the best possible consistent temperature read out.

It is important to mention that the FLIR ONE 2nd generation is not marketed as a measurement device, nor CE marked as a medical device.

Given all of these recent medical applications, it is the aim of this research to assess the accuracy (defined as offset or deviation from a known value) of the FLIR ONE 2nd generation cameras in terms of start-up offset drift and offset variations over the temperature range of the human skin.

Materials and Methods

The study took place in an environmental chamber of 2.5 x 4 m in size (controlled with a mean temperature of 24.0 ± 0.3 °C, relative humidity of 52.8 ± 4.3%, absence of incandescent lighting over all equipment and laminar low air flow) at the Faculty of Engineering, University of Porto. For image capturing four recently supplier-calibrated long wave (8 to 12 μm) thermal cameras FLIR ONE 2nd generation with a focal plane sensor array size of 80x60, a Noise Equivalent Temperature Difference of (NETD) of<100mK at 30°C and a measurement uncertainty of 5% of the overall reading in Celsius (-20 °C to 120°C) were used. Two were used with android over a micro-USB connection and the other two with iOS over an apple lightning connection. The first two were attached to a LG V400 Pad tablet and the other two to an iPad mini version 1. A recently calibrated and manufacturer calibration certificated valid blackbody Isotech Hyperion R Model 982 with a temperature range from -10°C to 80°C, resolution of 0.01 K, stability of 0.1 K and uncertainty of 0.1 K was used as reference source with an assumed emissivity value of 1.0. To verify the room environmental conditions a thermo-hygrometer Testo 175H1 with a digital display and capacity to store the mean temperature and relative humidity with resolution and uncertainty of 0.1 °C and 1% was used.

The tests of start-up offset drift and human body temperature range offset drift were performed by trained staff experienced in performing measurements from the blackbody source used. The emissivity parameter in the cameras was set to 1.0 value.

The start-up offset drift test consisted of setting the reference source to 30°C and waiting 2h to ensure its stability. The fully charged mobile devices were then switched on, the FLIR ONE app was executed, the FLIR ONE camera attached and at a distance of 30 cm and perpendicular to the blackbody surface, images were taken at 5 minute intervals for 1 hour. Only one camera could be used at a time, therefore the test was carried out on different days for each camera. Each camera was tested 5 times for the temperature sweep from 20°C to 40°C in 1°C steps, waiting 15 minutes at each step for a stable temperature. The IR cameras were kept on an external power supply during the whole procedure, and switched on 25 minutes before the first image was taken. At every temperature step just before the temperature was increased an image was taken with the software provided by the manufacturer. Each of the four cameras performed this test five times.

Example a thermal image taken from the reference source with the IR camera FLIR ONE 2nd generation is shown in figure 1.

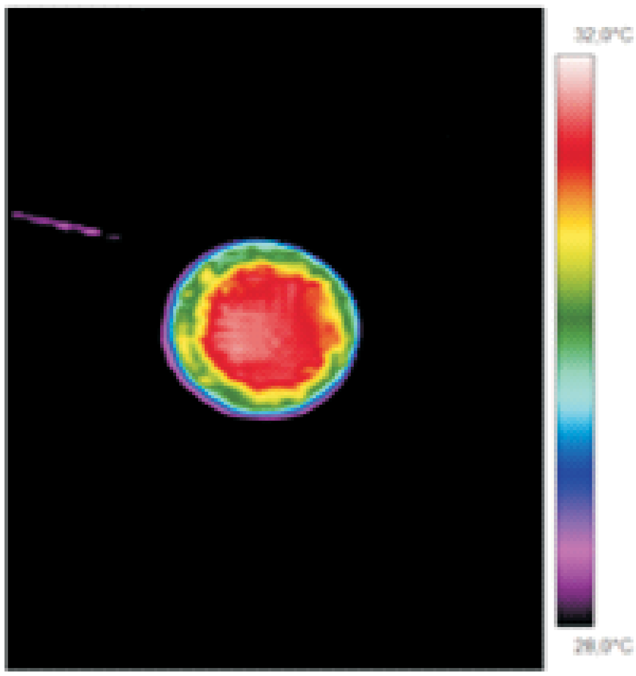


Figure 1
Example of an image taken from the calibration source (blackbody) at 30 °C with the IR camera FLIR ONE 2nd generation.

For assessing the images, a circular region of interest (ROI) was drawn in the images over the reference source circular temperature emission area, large enough for the measurement, in the software package FLIR ThermaCAM Researcher 2.10 pro. The emissivity setting of the cameras was set at 1.0 and the mean temperature of the ROIs was extracted.

Mean temperatures were organized in a Microsoft Excel spreadsheet and the statistical mean and standard deviation were calculated for both offset tests. Separated spreadsheets were also made for each connection type (USB and lightning). The Bland-Altman limits of agreement and Interclass Correlation Coefficient (ICC) were calculated between the average value of all measurements and the blackbody set temperature, each connection type camera average measurement and the blackbody set temperature and between the average measurements of the micro-USB connection type camera with the average measurements of the apple lightning connection type camera for the same blackbody set temperature.

Results

The measured values from the start-up offset drift test of all cameras and the two connection types are presented in table 1. In this section, the micro-USB connection camera is called "FLIR ONE 2nd generation for Android" and the Apple Lightning connection camera is called "FLIR ONE 2nd generation for iOS". Figure 2 shows a graphical representation of the measurement variability during the test. It can be observed that all camera measurements (20 assessments) tend to stabilise after 20 minutes, overestimating the reference source on average by 1.0 ºC. The 10 measurements from FLIR ONE 2nd generation for Android showed an average stabilisation time of 15 minutes, with a

Table1
The start-up drift test results.

Time (min)	All FLIR ONE 2nd generation measurements (4x5)	FLIR ONE 2nd generation for Android (2x5)	FLIR ONE 2nd generation for iOS (2x5)
1	31.4 ± 0.7	32.2 ± 0.2	30.8 ± 0.1
5	30.4 ± 2.6	30.1 ± 3.9	30.6 ± 0.1
10	31.2 ± 0.8	31.8 ± 0.3	30.7 ± 0.6
15	31.2 ± 0.6	31.6 ± 0.3	30.8 ± 0.5
20	30.9 ± 0.4	31.2 ± 0.1	30.6 ± 0.3
25	31.1 ± 0.7	31.6 ± 0.5	30.6 ± 0.4
30	31.0 ± 0.6	31.5 ± 0.1	30.5 ± 0.4
35	30.9 ± 0.6	31.5 ± 0.2	30.5 ± 0.4
40	30.9 ± 0.5	31.3 ± 0.3	30.6 ± 0.4
45	30.8 ± 0.6	31.2 ± 0.5	30.4 ± 0.3
50	30.9 ± 0.5	31.4 ± 0.2	30.5 ± 0.2
55	30.9 ± 0.5	31.3 ± 0.1	30.5 ± 0.3
60	30.3 ± 0.7	29.9 ± 0.9	30.6 ± 0.4

Figure 2
The variation of temperature readings from calibration source by the IR cameras FLIR ONE 2nd gen for iOS (blue), for Android (green) and all FLIR ONE 2nd gen average measurement (grey) during the start-up drift test, the yellow line represents the temperature of the calibration source (blackbody) and the red lines the measurement uncertainty limit.

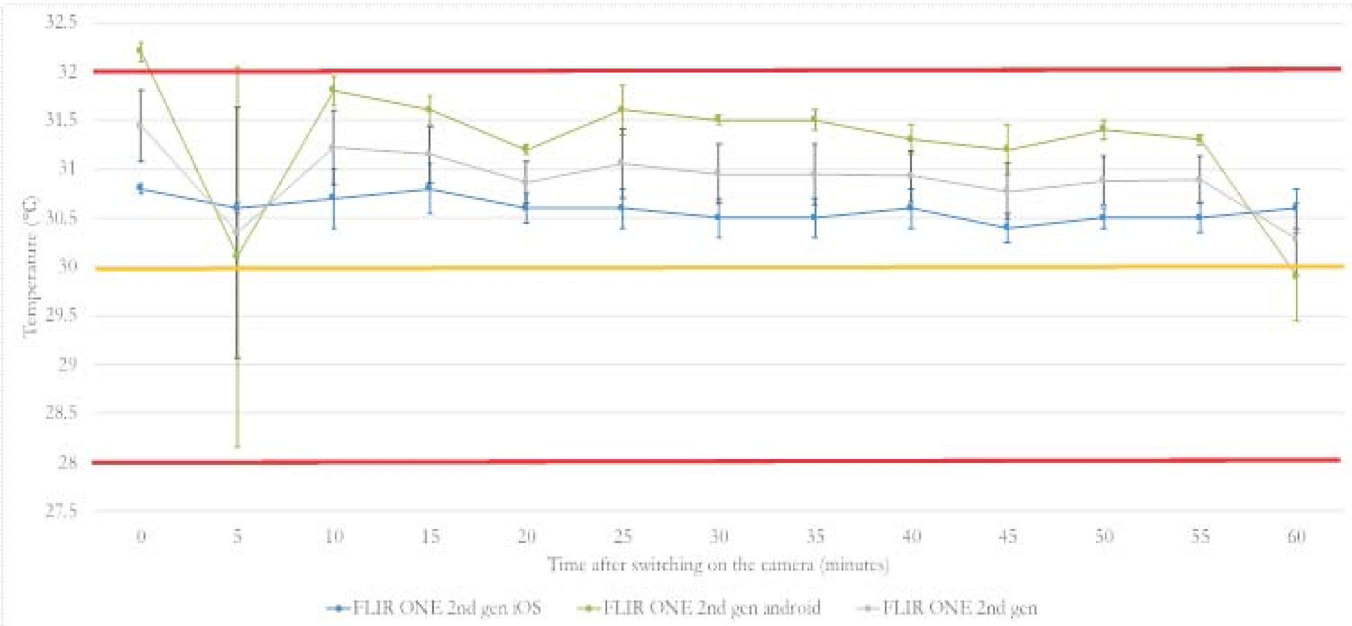
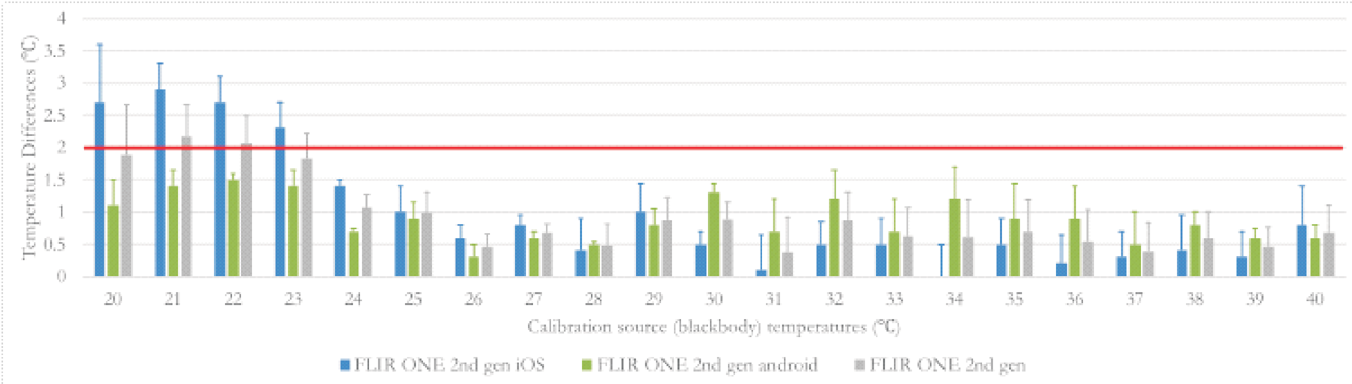


Figure 3
The difference between calibration source(blackbody) temperatures and the reading of IR cameras FLIR ONE for iOS (blue), for Android (green) and all FLIR ONE 2nd gen average measurement (grey) during the offset variation over a temperature range test. In red the 2ºC manufacturer uncertainty.



mean overestimation of 1.4 ºC when compared to the blackbody. The 10 measurements from FLIR ONE 2nd generation for Android showed an average stabilisation time of 15 minutes, with a mean overestimation of 1.4 ºC when compared to the reference source.

The average difference between the FLIR One 2nd generation 20 measurements from the four cameras and the blackbody is 0.9 ± 0.2 ºC for the start-up drift offset test. For the iOS cameras the 10 temperature assessments against the blackbody, the average difference is 0.6 ± 0.1 ºC and for the Android cameras 10 measurements the average difference from the temperature reference is 1.3 ± 0.6 ºC.

Figure 3 presents the difference between the measurements obtained from the four used cameras and the blackbody

Table 2
The offset variation over a temperature range test results.

Calibration Source (Blackbody) Temperature (ºC)	All FLIR ONE 2nd generation measurements (4x5)	FLIR ONE 2nd generation for *Android* (2x5)	FLIR ONE 2nd generation for *iOS* (2x5)
20.0	21.9 ± 1.6	21.1 ± 0.8	22.7 ± 1.8
21.0	23.2 ± 1.0	22.4 ± 0.5	23.9 ± 0.8
22.0	24.1 ± 0.9	23.5 ± 0.2	24.7 ± 0.8
23.0	24.8 ± 0.8	24.4 ± 0.5	25.3 ± 0.8
24.0	25.1 ± 0.4	24.7 ± 0.1	25.4 ± 0.2
25.0	26.0 ± 0.7	25.9 ± 0.5	26.0 ± 0.8
26.0	26.5 ± 0.4	26.3 ± 0.4	26.6 ± 0.4
27.0	27.7 ± 0.3	27.6 ± 0.2	27.8 ± 0.3
28.0	28.5 ± 0.7	28.5 ± 0.1	28.4 ± 1.0
29.0	29.9 ± 0.7	29.8 ± 0.5	30.0 ± 0.9
30.0	30.9 ± 0.5	31.3 ± 0.3	30.5 ± 0.4
31.0	31.4 ± 1.1	31.7 ± 1.0	31.1 ± 1.1
32.0	32.9 ± 0.9	33.2 ± 0.9	32.5 ± 0.7
33.0	33.6 ± 0.9	33.7 ± 1.0	33.5 ± 0.8
34.0	34.6 ± 1.1	35.2 ± 1.0	34.0 ± 1.0
35.0	35.7 ± 1.0	35.9 ± 1.1	35.5 ± 0.8
36.0	36.5 ± 1.0	36.9 ± 1.0	36.2 ± 0.9
37.0	37.4 ± 0.9	37.5 ± 1.0	37.3 ± 0.8
38.0	38.6 ± 0.8	38.8 ± 0.4	38.4 ± 1.1
39.0	39.5 ± 0.6	39.6 ± 0.3	39.3 ± 0.8
40.0	40.7 ± 0.8	40.6 ± 0.4	40.8 ± 1.2

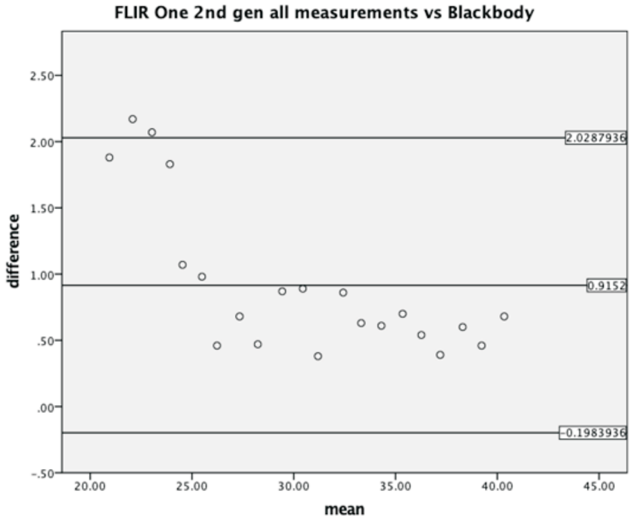


Figure 4
The limits of agreement between the mean values measured by all the FLIR ONE 2nd generation cameras and the calibration source (blackbody) during the human body temperature range.

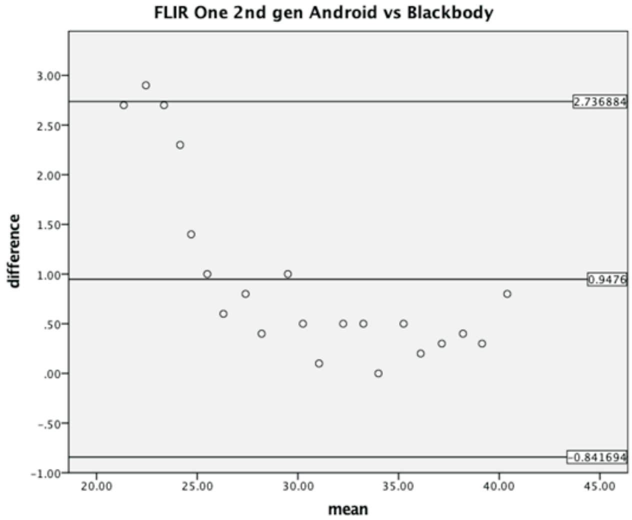


Figure 5
The limits of agreement between the mean values measured by the FLIR ONE 2nd generation camera for android and the calibration source (blackbody) during the human body temperature range.

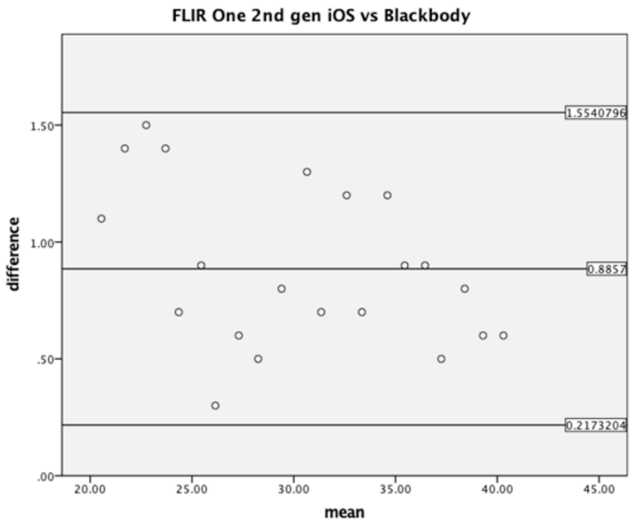


Figure 6
The limits of agreement between the mean values measured by the FLIR ONE 2nd generation camera for iOS and the calibration source (blackbody) during the human body temperature range.

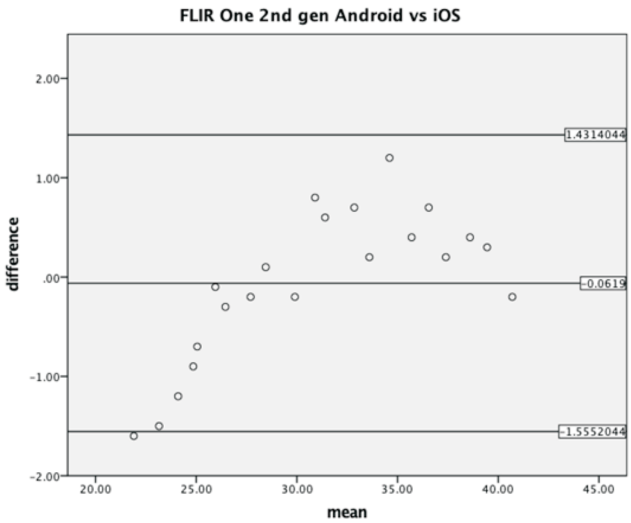


Figure 7
The limits of agreement between the mean values measured by the FLIR ONE 2nd generation camera for android and the calibration source (blackbody) during the human body temperature range.

Table 3
The Interclass Correlation Coefficient between the measurements during the human body temperature range.

Measurements	Cronbach' Alpha coefficient	ICC	ICC (95% c.i.)
All FLIR One 2nd generation measurements and blackbody	0.998	0.996	0.989 to 0.998
FLIR One 2nd generation for *Android* and blackbody	0.994	0.988	0.971 to 0.995
FLIR One 2nd generation for *iOS* and blackbody	0.999	0.998	0.996 to 0.999
FLIR One 2nd generation for *Android* and FLIR One 2nd generation for *iOS*	0.996	0.991	0.979 to 0.996

during the temperature sweep grouped by all 20 assessments of all cameras, the 10 assessments of iOS cameras and the 10 assessments of Android cameras. Table 2 presents all 20 assessments of all cameras, 10 assessments of iOS cameras and 10 assessments of Android cameras of the blackbody referencing the temperatures between 20 ºC and 40 ºC. In the temperature range of 20 ºC to 23 ºC, a maximal deviation of all camera measurements from the blackbody temperature was observed, exceeding 2 ºC. The difference for all iOS was greater than 2.2 ºC and for all Android greater than 1.7 ºC. In the temperature range of 25 ºC to 40 ºC all differences are lower than 1.0 ºC, excluding all the Android camera at temperatures 30 ºC, 32 ºC and 34 ºC.

The maximum deviation between the blackbody temperature and 20 measurements from the four FLIR ONE 2nd generation cameras is 0.9 ± 0.6 ºC, for the temperature sweep being of 2.2 ºC. For the 10 iOS cameras temperature assessments against the blackbody, the average difference is 0.9 ± 0.9 ºC, with maximum of 2.9 ºC. In 10 Android camera measurements the average difference from the blackbody temperature is 0.9 ± 0.3 ºC, with a maximum of 1.5 ºC.

Figure 4 presents the Bland-Altman limits of agreement between the 20 temperature measurements of all the FLIR ONE cameras and the value indicated by the blackbody during the temperature sweep. The mean difference to absolute agreement between the blackbody and all 20 temperature measurements is 0.91 ºC, the limits of agreement (LOA) rank between - 0.2 and 2.03°C. Mean bias to agreement with the calibration reference was 0.95 (figure 5) in the 10 temperature measurements of the android cameras, with a span of LOAs equal to 3.58 °C. The 10 temperature measurements with the iOS cameras obtained a mean difference to the blackbody temperature of 0.89 ºC (Lower LOA: 0.21°C, Upper LOA: 1.55°C; figure 6). Comparing measurements from Android cameras with temperature readings from iOS cameras resulted in a small mean bias of -0.6 °C (Lower LOA: 0.21°C, Upper LOA: 1.55°C; figure 7)

The Interclass Correlation Coefficient analysis (table 3) shows good data consistency (Alpha Cronbach' coefficient > 0.995) and evidence of relationship (ICC > 0.990) between all the 20 measurements of all FLIR ONE cameras and blackbody, all the 10 measurements of the iOS cameras and calibration reference values, all the 10 assessments of the Android cameras and the blackbody temperature and between the 10 measurements of the iOS cameras and 10 assessments of the Android cameras.

Discussion

This study has followed the IRT imaging guidelines (3-6) with respect to examination room and equipment preparation. In the start-up drift test, it is verified that the FLIR ONE 2nd generation cameras stabilised their output only after about 15 to 20 minutes after being switched on. This limits their time of use since their battery lasts about 1 hour. The average difference obtained after 20 measurements of four instruments is 0.9 ºC. When comparing the two imager connection types (micro-USB for Android devices and Apple Lightning for the iOS devices), the iOS version outperforms the Android version. The Android cameras seem to stabilise faster than the iOS cameras. The differences may be related to the software differences between the two devices or due to the sensor itself. The underlying sensor (Lepton) uses a SPI bus to communicate serial data to a microcontroller. This data must then be translated into USB/Lightning or USB/micro-USB connection compatible data which can then be read by the smartphone/tablet. Over the course of the communication, a Cyclic Redundancy Check (CRC) is enforced to ensure that the data does not get corrupted in transit (19). Additionally, it is possible that the software between the smartphone/tablet application is slightly different as well as the microchip that reads out the lepton sensor data. However, without opening the device (which voids the warranty) and attaching the lepton sensor to an SPI bus and reading out the sensor data and settings directly, it is not possible to say where these differences in the data arise. Using FPA stabilisation techniques has shown to provide consistent temperature values (20) on evaluations against blackbodies at the National Physical Laboratory in the United Kingdom.

In the temperature sweep, the 20 measurements of all FLIR ONE 2nd generation cameras presented an average error of 0.9 ºC and a maximum error of more than 2ºC. The two connection type versions of the thermal cameras studied presented similar results, where the iOS version had slightly higher variation, but the high ICC proves the relationship between the measurements through statistical evidence.

It is important to note that these deviations are within the manufacturer provided specifications, being the differences due to random characteristics of the individual cameras rather than systematic connection type or operation system differences.

The finding of this research is in line with those presented by Curran et al. (14), where an average error of 1 ºC is presented by overestimation of temperature.

Based in this finding the claims presented in the clinical studies (11-13,15-18) using this kind of cameras are difficult to be acknowledged. It is important to note that when collecting data with these cameras the uncertainty in the evaluation of thermal images in medicine is not only affected by the camera itself, factors (21) such as individual data of participants and their preparation for thermal imaging; extrinsic factors such as recent physical activity or physiotherapy; wetness of the skin; ambient temperature, humidity and infrared sources in the examination space, acclimation time, camera type, camera settings, emissivity, size of field of view, camera position in relation to the imaged subject and image analysis are sources of uncertainty and to overcome this; IRT imaging guidelines (3-6) should be followed to minimize their effect. However, it is also important to note that this imaging system's operational performance is not in conformity with the required standards for clinical applications (8,9).

The tests presented in this research do not intend to be technical, they are based on an end user with minimal experience but with the capability of repeating it since there is access to a manufacturer calibrated blackbody to perform similar examinations.

Conclusion

Despite these systems being attractive in price (around 300.- Eur) and manufacturer provided features, their operational performance does not comply with required standards for clinical use. The thermal information provided by these imaging systems should only be taken into account for monitoring purposes, as some previous research demonstrated, and not as an input for diagnostic judgments, if they require absolute temperature values to be correct. It is important to note that the cameras provider does not advertise them as medical devices.

Acknowledgements

The authors gratefully acknowledge the partial funding of Project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, cofinanced by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER) and the FCT - Foundation for Science and Technology under the project (PEst-OE /EME/LA0022/2013).

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(Received on 11.10.2018, revision accepted on 8.08.2019)