SEEKAR TECHNOLOGIES

Verification Testing Report

TrueDepth Camera

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Verification Report Seekar Technologies Mobile Thermometer Application Thermo

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1.0 Purpose

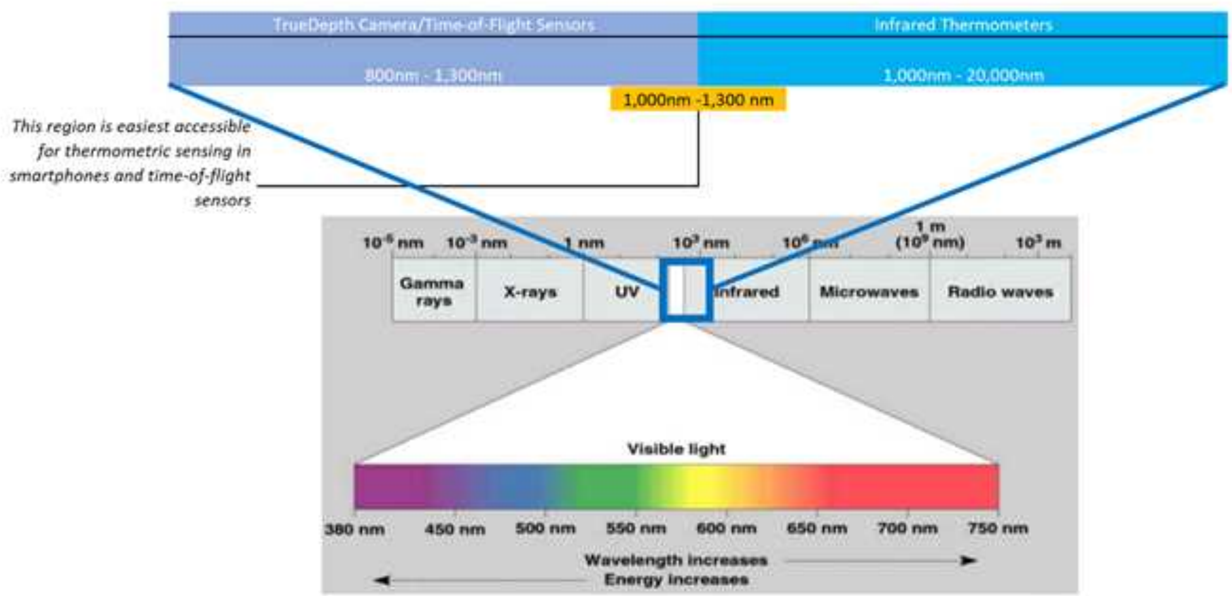
This report is for verification purposes. Seekar Technologies evaluates the practicality and potential of using the Apple TrueDepth camera on modern common iPhones to perform thermometric readings. This report outlines the materials and procedures used to perform the evaluation. We propose that Apple's TrueDepth camera retains the capability of providing accurate temperature readings of nearby objects due to the underlying physics of the camera itself. Particularly, the Apple TrueDepth camera may provide an epidermal thermometer reading of a human for the purposes of medical screening.

2.0 Hypothesis

For any measurable subject within the optical field of view at a fixed distance, the Apple TrueDepth camera returns different depth measurements for that subject as that subject's temperature fluctuates.

3.0 Background

Many modern smartphones and tablets use built-in infrared sensors for facial recognition, iris recognition, and other security features. While the purpose of these sensors are specifically designed for security purposes, some mobile applications (apps) make use of them for augmented reality applications as well. In these applications, the infrared sensor is being used to return depth information about the user's face. For example, Apple's TrueDepth infrared sensor (this sensor is commonly known as FaceID) projects 30,000 infrared dots onto the user's face looking for a specific pattern in the distances of those dots. This is typically known as a time-of-flight sensor as it is emitting the infrared series and calculating the time it takes for each of those 30,000 dots to return back to the detector (i.e. the dots are "in flight"); the difference in times between the dots at each point of emission gives distance, allowing the sensor to construct a very detailed depth map of the sensor's field of regard. However, Seekar has shown success in being able to reprogram the sensor to be able to act as a thermometer as well. Instead of explicitly returning distance, extensive experimentation carried out by Seekar has shown that an obvious underlying relationship exists between the returned depth data of these onboard smartphone sensors and their variation in measurement with temperature changes in the object they measure. In other words, the depth that the TrueDepth camera specifies at any one particular distance varies depending on the temperature of the object any one of the 30,000 infrared dots is focused on. Seekar has integrated this functionality into an app that allows the user to scan their face and get a temperature reading of their skin. For example, standard contactless infrared thermometers typically utilize infrared energy with a wavelength in the 700 – 20,000 nm region. Apple's TrueDepth time-of-flight sensor utilizes infrared that operates in the 800 – 1300 nm region. This leaves a 300 nm overlap in which the time-of-flight sensor may show a higher reactivity to temperature and serve a dual purpose as a contactless thermometer. To determine temperature, infrared energy is concentrated from an object's surface to a detector called a thermopile. This thermopile absorbs this infrared energy, and then an onboard computer converts the absorbed energy into heat. The more that is received, the higher the temperature reading. Additionally, different objects return different temperature readings for the same concentration of infrared energy. This is governed by an object's emissivity. For example, the same amount of infrared energy focused on black steel will return a slightly different reading than if it was focused on white rubber; this is because steel and rubber have different emissivities. The Stefan-Boltzmann Law was used to factor in the emissivity into the temperature calculations (the Stefan-Boltzmann Law is a physics law that succinctly interprets the association between emissivity, heat, and wavelength). The diagram below shows the band of infrared energy utilized by Seekar for the purposes of the measurements presented in this report.



For the purposes of Seekar's application, we have programmed the sensor to accurately return temperature numbers based on the emissivity of human skin only. Future work may entail accommodating other object materials as well.

As previously stated, infrared thermometric readings utilize a certain wavelength of the infrared spectrum in order to detect the infrared energy emitted from certain objects. In most consumer contactless infrared thermometers, this wavelength is between 700 – 20,000 nm. Since different materials radiate different amounts of infrared energy, Seekar used aluminum (1235 alloy), ABS plastic, and leather to use as the objects of interest for temperature reading. Leather was used because it is a commodity material that most closely represents human skin, while aluminum and plastic were used to analyze the effectiveness of the experiment on different materials. The emissivity of the material of the object of interest is a critical component to infrared temperature readings. Finally, a REED BX-500 blackbody infrared thermometer calibration instrument was used to establish ground truth measurements and act as further validation.

4.0 Materials

Table 1 - List of materials.

#	Component	Qty	Description
1	Apple iPhone 12 Pro Max	1	Test device (S/N F2LDN5QQ0D46)
2	Metal Vice	1	Constrains the thermal heat gun
3	Industrial heat gun (model no. H-915)	1	Heats up test samples
4	Metal constraint locks	1	Constrains component positions on Pegboard table
5	Sliding rail	1	Allows test subjects to be easily interchanged
6	30cm x 45 cm strip of cowhide leather	2	Test sample emulating human skin
7	30cm x 45cm piece of aluminum foil	1	Test sample, aluminum alloy 1235
8	30cm x 45cm piece of plastic	1	Test sample, ABS plastic
9	PC868 FDA 510(k) Approved contactless IR thermometer gun[5]	1	Control device
10	Carpenter’s contactless IR thermometer gun	1	Control device
11	Measuring and data logging iOS application	1	Seekar-developed iOS app that allows raw data to be gathered from TrueDepth camera
12	Measuring tape	2	Used to get ground-truth distances from test subjects
13	Tripod structures	2	Constrains iPhone and IR thermometers
14	Pegboard table	1	Workspace that allows all components to be locked into place
15	Support beam	1	Used to support Vice and constrain its position

16	Backing Plate	3	Used to support and constrain the test samples
17	Gyroscopic Level	1	Used to ensure the iPhone is leveled and locked in all 6 DOF.
19	REED BX-500 Black Body Instrument	1	Used as a black body to receive ground truth temperature measurements.
20	Black Body Standoff	1	Used to position the REED BX-500 at appropriate height.
21	Spacers	3	Spacers used to position the REED BX-500 at appropriate height.

5.0 Laboratory Setup

5.1 Setup I

Three test samples were used to test the hypothesis. The goal was to gather data and correlations for different materials and different emissivities. The three materials measured were cowhide leather, aluminum, and ABS plastic. The team preferred to perform measurements on

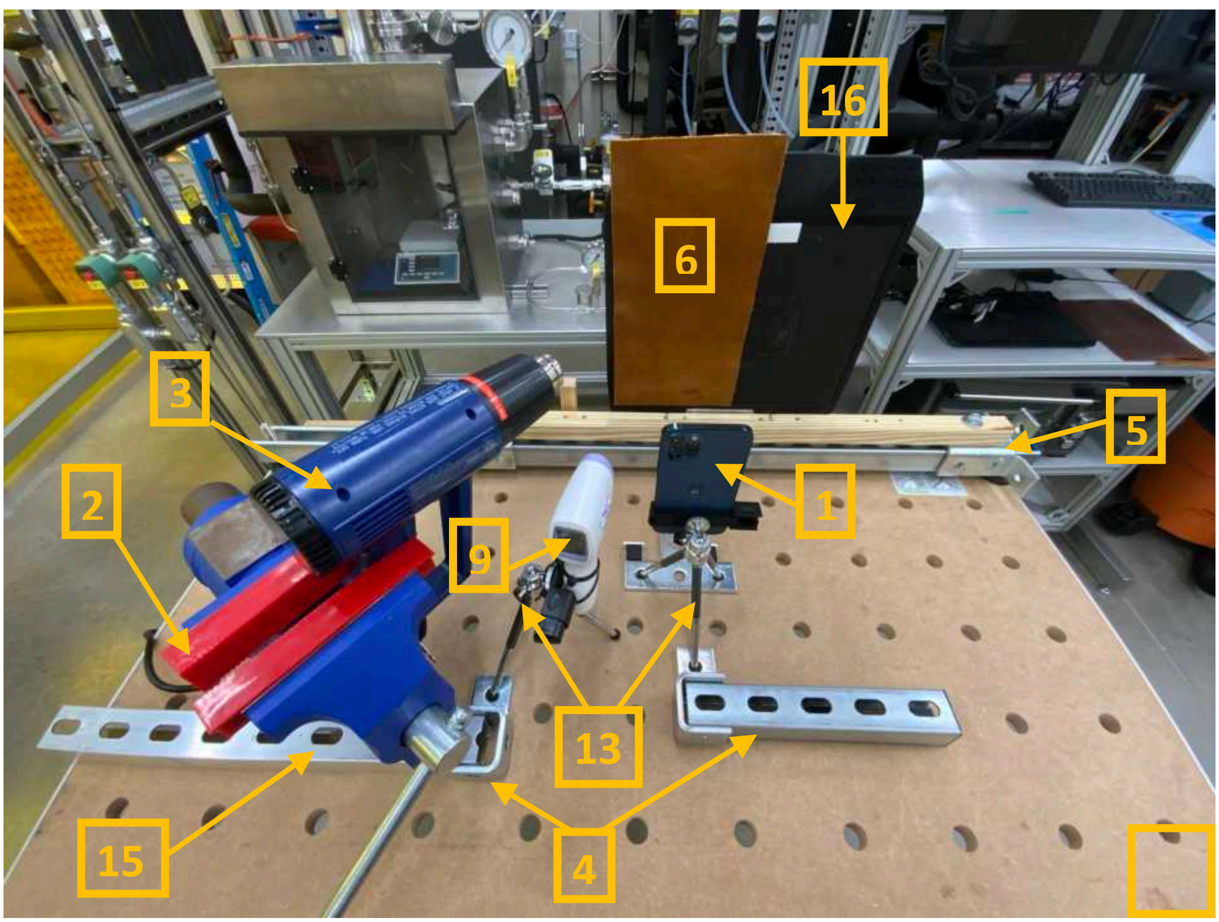


Figure 1 - Setup of components for first experimental trials, aft view.

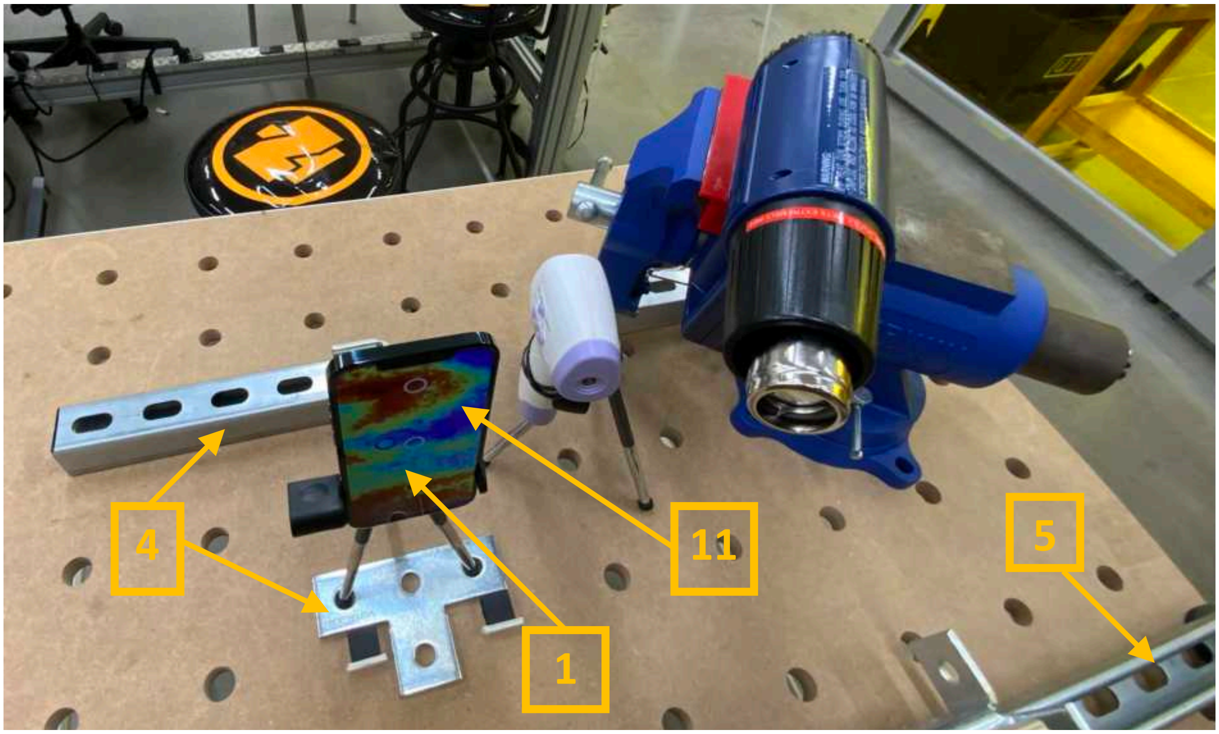


Figure 2 - Setup of components for first experimental trials, front view.

actual human subjects, but it was quickly shown to be infeasible to have human subjects remain still for the duration of the experiment while not moving so much as even a millimeter. Because of this, cowhide leather was used in place of human skin due to the fact that its emissivity and physical properties were the closest we could easily accumulate in a raw material.

Each of the three test samples was set attached to a backing plate and set at a fixed distance from the TrueDepth camera. Previous experimentation showed that the best thermal response is achieved when the test subject is placed between 15 cm and 27 cm away from the TrueDepth camera. The plastic material sample was the first subject to be tested followed by aluminum, and then leather. The subject was placed a distance *d = 204 mm* from the iPhone and a gyroscopic level was used to ensure that its planar face was perpendicular to the field of view of the TrueDepth camera. In other words, the measured face of the test sample was placed parallel to the screen of the iPhone containing the TrueDepth camera. The PC868 infrared thermometer gun was placed at an equivalent distance away from the test subject such that the TrueDepth camera detector and the detector of the gun were both at identical 204 mm distances from the subject.

The figure below shows a cross-section of the TrueDepth camera field-of-view.

One can see that the 204 mm distance represents both (1) the distance between the TrueDepth camera detector and the test subject, and (2) the distance between the IR thermometer gun detector and the test subject. This distance is very important to note as it never changes and remains constant throughout the entire experiment. The distance does change as test subjects are replaced between measurement tests, but it remains unchanged throughout the entire measurement sequence for a single subject. The camera gyroscopes were also sampled to ensure that the camera field-of-view was orthogonal to the test subject within +/- 0.1°, the

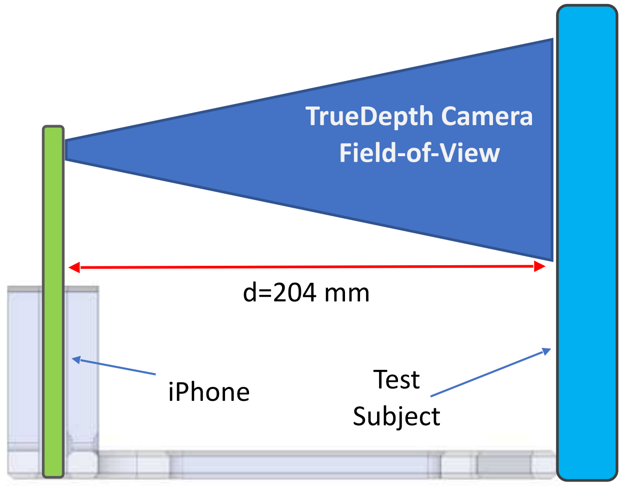


Figure 3 - Cross-section showing iPhone TrueDepth camera field-of-view.

camera field-of-view was parallel to the table within +/- 0.1°, and that the iPhone itself was parallel to the gravitational vector (or completely vertical) within +/- 0.1°. An identical leveling procedure was followed for the infrared thermometer gun as well.

Additionally, an actual image captured from the experimental setup further illustrates the controlled distance. Refer to the image below for a bird's-eye-view of the aforementioned setup.

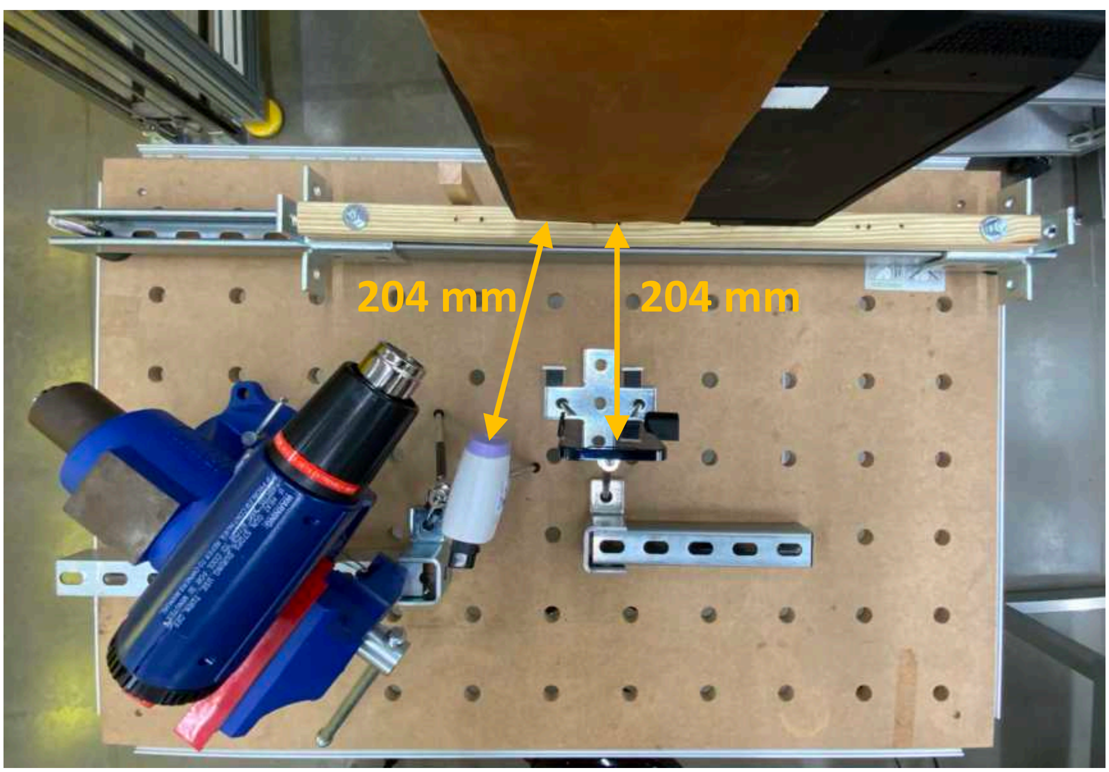


Figure 4 - Setup of components for first experimental trials, bird's-eye view,

The above setup was repeated for each of the three test material samples - leather, plastic, and aluminum.

5.2 Setup II

In order to establish ground truth temperature measurements, Seekar also found it prudent to perform an identical procedure against a black body temperature calibrator. The instrument utilized in this regard was a *REED BX-500 Infrared Temperature Calibrator.* The instrument is pictured below and more information on its functionality may be found in *Source 4* in the *References* section*.* The *BX-500* instrument is pictured below.

Figure 5 - REED BX-500 infrared calibrator.

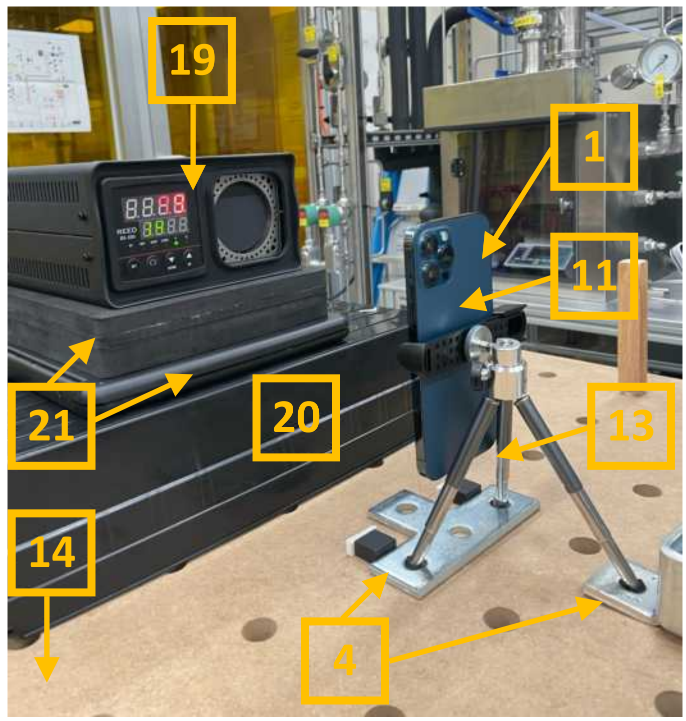


Figure 6 - Setup of components for second run of experimental trials against the infrared calibrator.

There are five points within the TrueDepth camera field of view that are measured. Since there are 30,000 infrared beams cast from the TrueDepth camera, there are essentially 30,000 points of measurement. This experiment is focused on obtaining the measurement at a specific beam or specific subset of beams out of the entire field of view. To accomplish this, the coordinates of each infrared beam were mapped to a square area within the iPhone screen coordinate frame. Five regions to measure were determined and, although data for all 30,000 infrared beams were acquired, only beams within the five regions were analyzed. It's worth noting that for each of these five regions, a cluster of infrared beams is analyzed and their values averaged for a single return value. A screenshot of the field of view as visualized from the user interface of the app is shown below. The five regions are indicated by hollowed out circles of different colors. Each region is coded as *1, 2, 3, 4,* or *5* for easier interpretation of the results.

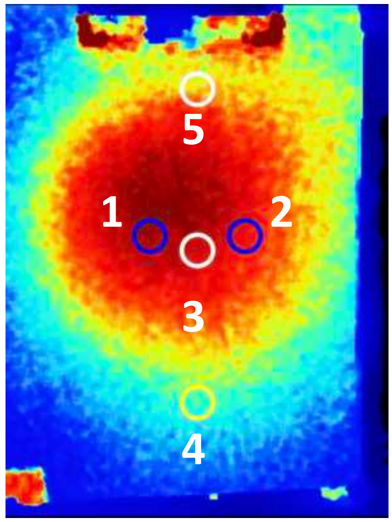


Figure 7 - Screenshot of the Seekar iOS mobile app showing the measurement locations of the clusters of infrared beams being measured throughout experimental trials.

6.0 Procedure

6.1 Testing Procedure

(1) The test began by initializing the measuring and data logging app on the iPhone 12 Pro Max. The app gathers raw distance data from the TrueDepth camera and logs these distances every 5 seconds to a .csv file within the app. Simultaneously, a lab member gathers measurements with the mentioned infrared thermometer every 10 seconds. A timer that is controlled by the app synchronizes both measurements together so we can ensure that temperature measurements documented at a certain timestamp match the timestamp of the distance measurement received on the iPhone. This procedure was performed for 60 seconds just measuring the subject in ambient air.

(2) After 60 seconds, the thermal heat gun was activated and began applying heat of 150°F to the subject. The heat gun remained on for another 60 seconds while measurements were taken in the manner above in (1).

(3) After another 60 seconds (120 seconds total elapsed time), the heat gun was deactivated and the subject was allowed to cool for 60 more seconds. Again, measurements were taken in the manner described in process (1).

(4) Processes (2) and (3) were repeated two more times each such that the total elapsed time resulted in 420 seconds with an ambient phase, three heat-up phases, and three cool-down phases. Please reference the diagram below for a graphical representation of the procedure performed.

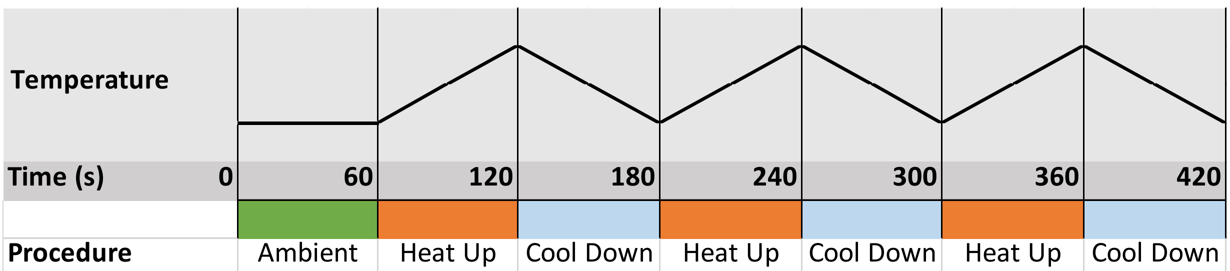


Figure 8 - Heating and cooling procedure for first experimental trials.

The procedure above was repeated for the remaining test material samples of aluminum and leather. The thermal heat gun was controlled to the same heat setting every time without adjustment. Results for each test sample are discussed in the next section.

6.2 Mathematical Procedure

The emitted and detected signals are recorded by synchronously demodulating the incoming modulated light wave within the detector. The emitted and detected signals show a phase delay that is characterized well by the equations below[1, 2]. For a given reference signal *g(t)* and its incident signal *s(t),* the cross correlation function *c(T)* between the two signals for a given phase delay *T* is given by:

$$c(\tau) = (s \times g)(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} s(t) g(t+\tau)\, dt$$

Consider a sinusoidal signal $g(t) = cos(\omega\ t)$ and its reflected signal[3] $s(t) = h + a\cos(\omega\ t + \phi)$. Through trigonometric identities, one receives a correlation function $c(\tau) = h + \frac{a}{2}\cos(\omega\ t + \phi)$ in which ω, ϕ, *a,* and, *h* are the modulation frequency, phase shift relating to the distance of the object; amplitude of *s(t)*, and offset of *s(t)* respectively.

To compute ϕ we select four phase delays, $\tau_0, \tau_1, \tau_2, \tau_3$ in consideration with the correlation function:

$$\phi = \arctan(\frac{c(\tau_3) - c(\tau_1)}{c(\tau_0) - c(\tau_2)})$$

For the amplitude and offset of the incident signal, *a* and *h,* may be calculated as shown:

$$a = \frac{\sqrt[2]{[c(\tau_3) - c(\tau_1)]^2 + [c(\tau_0) - c(\tau_2)]^2}}{2} \qquad h = \frac{c(\tau_0) + c(\tau_1) + c(\tau_2) + c(\tau_3)}{4}$$

Considering these equations altogether, one can show that the amplitude *a* can be interpreted as a direct measure of the depth resolution *d* achieved by the signal.

$$d = \frac{c\phi}{4\pi\omega}$$ **Equation (1)**

With the execution of this experiment, Seekar shows that perceived depth resolution varies with temperature and emissivity changes such that a different set of measured temperature and emissivity values will return a different phase shift ω consequently providing a different depth resolution *d.* Therefore, we show that, for the Apple TrueDepth camera specifically, the above equation holds only as a function of the specific temperature and emissivity of the object being measured.

$$d(\kappa, \epsilon) = \frac{c\phi}{4\pi\omega}\kappa\epsilon$$ **Equation (2)**

Where κ and ϵ are, respectively, constants representing the current temperature and emissivity of the contact surface of the measured object. This report attempts to confirm the validity of Equations (1) and (2) while also attempting to quantify κ and ϵ.

Expressed differently, Seekar attempts to confirm that the temperature of an object being measured by the TrueDepth camera over the specific electromagnetic wavelength influences the amplitude and/or wavelength of the returned time-of-flight infrared beam such that the same object being measured at a specific distance will return a different perceived distance as the temperature of that object changes. This effectively allows a time-of-flight sensor to interpret temperature readings[1].

7.0 Data Preprocessing

Temperature and distance data are recorded in different units. Therefore, in order to try to derive a causality, it isn't effective for one to simply look at temperature data and distance data side by side. In order to equivocally compare the two different data types, each data type was put through a process called *normalization* which expresses each value as a percentage of the observed values on the range of the minimum and maximum values of the dataset. The equation used to arrive at each analyzed value *x* can be seen below:

$$x_{temperature} = \frac{t - min(T)}{max(T) - min(T)},$$

Where *t* is defined by the original observed temperature measurement, and *T* is defined as the subset of temperature measurements taken for the pertinent experiment such that each value *t* within *T* is a definite positive floating-point number. Identically, a similar process is performed above for distance data:

$$x_{distance} = \frac{d - min(D)}{max(D) - min(D)},$$

Where *d* is defined by the original observed distance measurement, and *D* is defined as the subset of distance measurements taken for the pertinent experiment such that each value *d* within *D* is a definite positive floating-point number. As we will see in the *Results* section, the returned distance values have an *inverse* relationship with the temperature change. In order to synchronize the data, we subtract each normalized value from 1, leaving temperature unchanged as the control data.

[1] The authors thought it prudent to ensure that responses observed were not a consequence of reflected light rather than temperature change of the object being measured. Due to this, the Seekar performed experiments in both well-lit areas and dark areas with nearly no light whatsoever. The results between these tests had seemingly no effect on the data observed.

These procedures allowed both temperature and distance values to be easily plotted together on the same graph over the range *[0, 1].*

8.0 Results

8.1 Results - Setup I

Plastic - Target Emissivity: 0.92

The data summary for plastic may be seen below. Each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the dark blue line, and four of the regions accumulated from the TrueDepth camera field of view are defined by *cluster_#.*

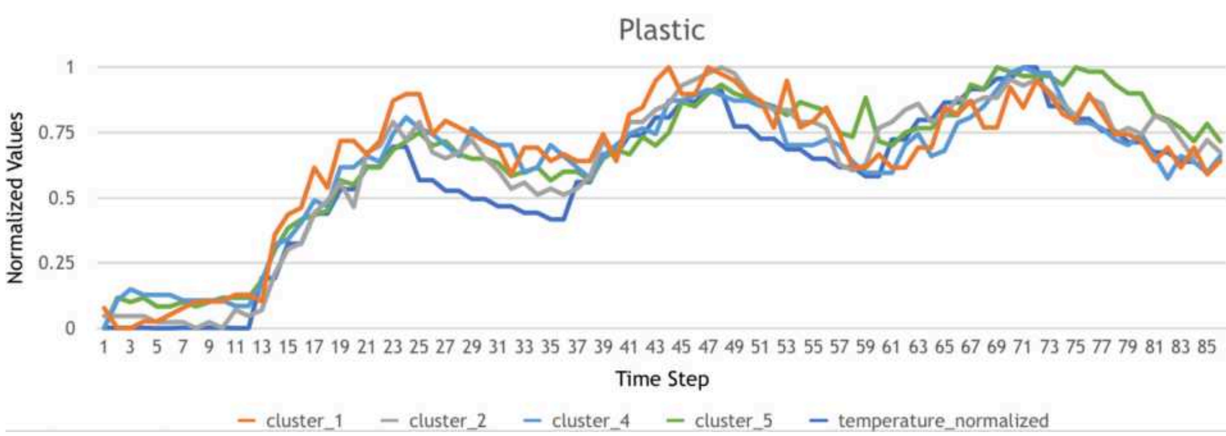


Figure 9 - Results of distance values returned from the TrueDepth camera and temperature values measured on the plastic subject material.

The procedure followed in *Section 6.0* is provided again for comparison:

Temperature							
Time (s) 0	**60**	**120**	**180**	**240**	**300**	**360**	**420**
Procedure	Ambient	Heat Up	Cool Down	Heat Up	Cool Down	Heat Up	Cool Down

Figure 10 - A reference to the heating and cooling procedure used for this test.

One can see that for the first 12 measurements (60 seconds in time), the values for each infrared cluster region are relatively stable just as the ambient temperature. As the first heat-up sequence begins, the returned values from the TrueDepth camera increase in lock-step with the temperature increase. At measurement 24 (120 seconds in time), one can see that the returned values from the TrueDepth camera also begins to decrease just as the temperature. One can observe this same correlation for two more full *Cool Down* and *Heat Up* cycles.

The maximum correlation between the temperature signal line and the distance signal line was 97.43% and was received over *cluster_3.* This is the region analyzing the TrueDepth camera at its center point. The minimum correlation received was 92.32% and was received over *cluster_1,* the left-most region of the five regions.

Aluminum - Target Emissivity: 0.03

The data summary for aluminum may be seen below. Each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the dark blue line, and four of the regions accumulated from the TrueDepth camera field of view are defined by *cluster_#.*

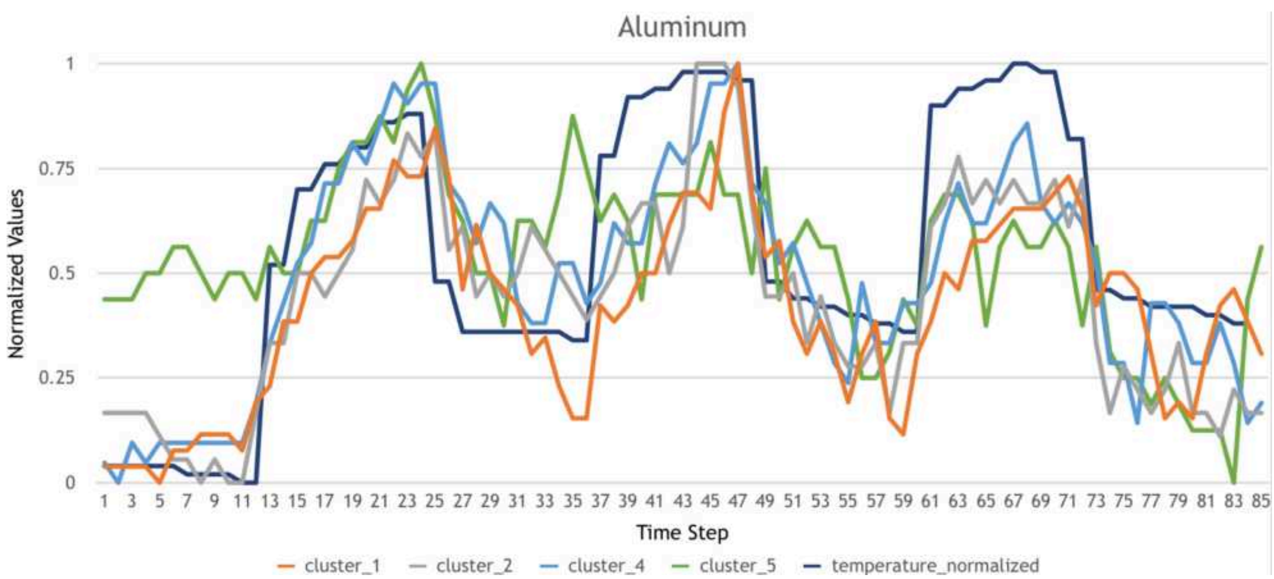


Figure 11 - Results of distance values returned from the TrueDepth camera and temperature values measured on the aluminum subject material.

The procedure followed in *Section 6.0* is provided again for comparison:

Temperature								
Time (s)	**0**	**60**	**120**	**180**	**240**	**300**	**360**	**420**
Procedure		Ambient	Heat Up	Cool Down	Heat Up	Cool Down	Heat Up	Cool Down

Figure 12 - A reference to the heating and cooling procedure used for this test.

One can see that for the first 12 measurements (60 seconds in time), the values for each infrared cluster region are relatively stable just as the ambient temperature. As the first heat-up sequence begins, the returned values from the TrueDepth camera increase in lock-step with the temperature increase. At measurement 24 (120 seconds in time), one can see that the returned values from the TrueDepth camera also begins to decrease just as the temperature. One can observe this same correlation for two more full *Cool Down* and *Heat Up* cycles.

The maximum correlation between the temperature signal line and the distance signal line was 84.39% and was received over *cluster_3.* This is the region analyzing the TrueDepth camera at its center point. The minimum correlation received was 80.64% and was received over *cluster_1,* the left-most region of the five regions.

Leather - Target Emissivity: 0.98

Trial I

The data summary for leather may be seen below. Each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the dark blue line, and four of the regions accumulated from the TrueDepth camera field of view are defined by *cluster_#.*

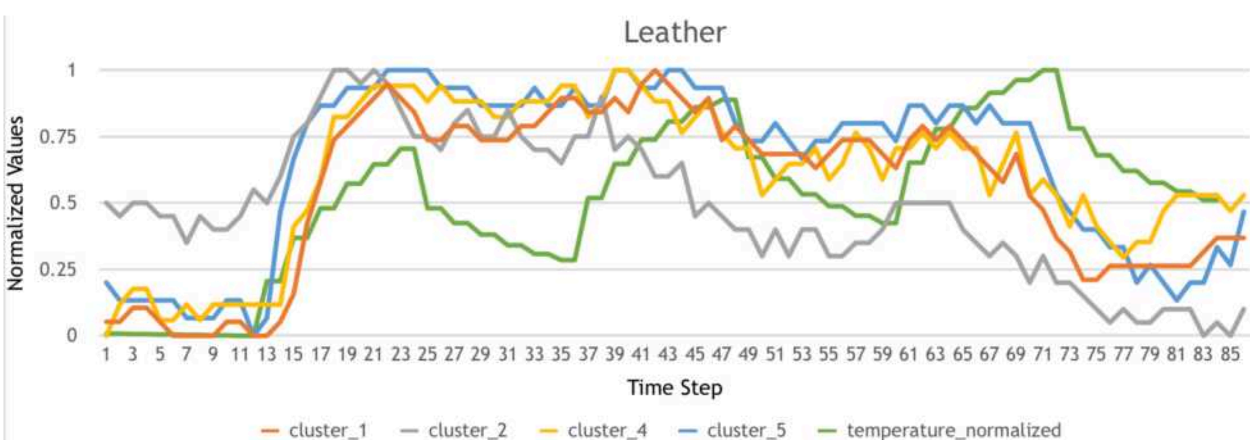


Figure 13 - Results of distance values returned from the TrueDepth camera and temperature values measured on the leather subject material, first trial.

The procedure followed in *Section 6.0* is provided again for comparison:

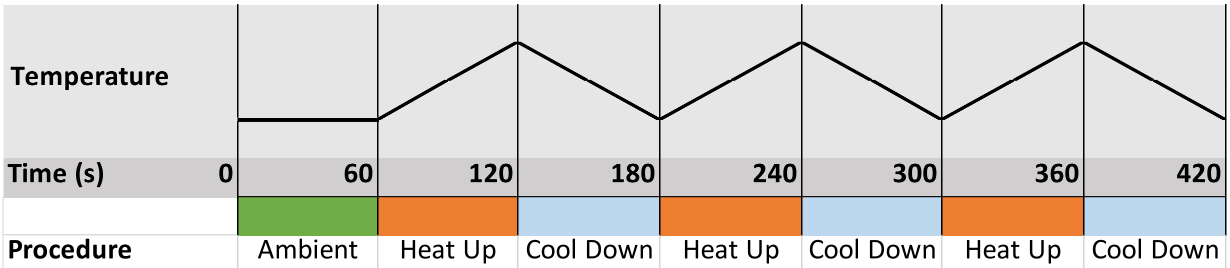


Figure 14 - A reference to the heating and cooling procedure used for this test.

One can see that for the first 12 measurements (60 seconds in time), the values for each infrared cluster region are relatively stable just as the ambient temperature. As the first heat-up sequence begins, the returned values from the TrueDepth camera increase in lock-step with the temperature increase. At measurement 24 (120 seconds in time), one can see that the returned values from the TrueDepth camera also begins to decrease just as the temperature. One can observe this same correlation for two more full *Cool Down* and *Heat Up* cycles.

The maximum correlation between the temperature signal line and the distance signal line was 56.72% and was received over *cluster_3.* This is the region analyzing the TrueDepth camera at its center point. The minimum correlation received was 56.19% and was received over *cluster_4,* the left-most region of the five regions.

Trial II

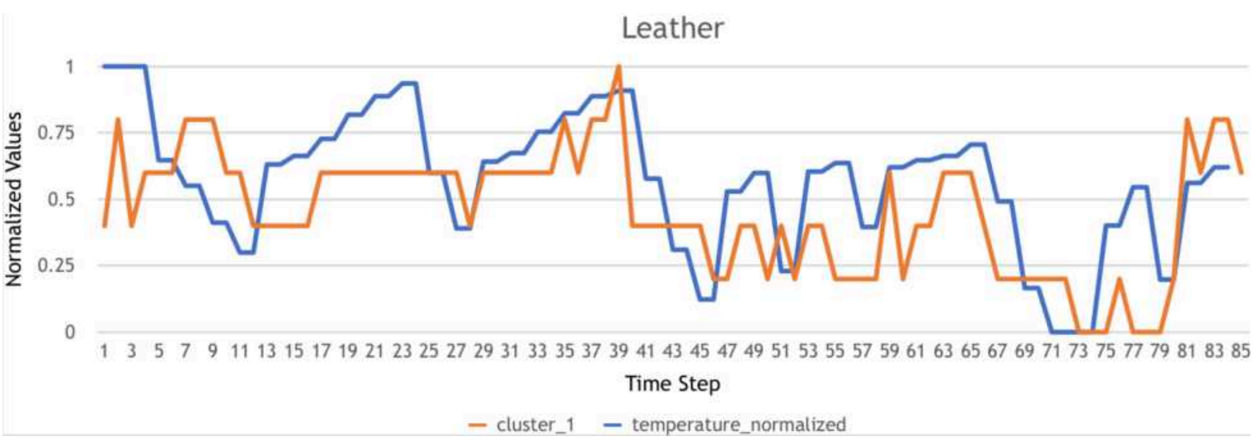


Figure 15 - Results of distance values returned from the TrueDepth camera and temperature values measured on the leather subject material, second trial.

The maximum correlation between the temperature signal line and the distance signal line was 58.16% and was received over *cluster_1.*

8.2 Results - Setup II

Infrared Calibration Instrument - Target Emissivity: 0.95

The data above shows a strong correlation between the temperature of an object and the TrueDepth camera's consequential response. In order to further verify the science and algorithm's behind Seekar's software, an industry-standard infrared thermometer calibration instrument was acquired, the *REED BX-500 Blackbody Infrared Calibrator.* This allowed our methods of calculation and evaluation to be verified against a ground-truth method that is used by infrared thermometer manufactures to calibrate their products. A data summary for the instrument may be seen below. The heating and cooling procedures followed for this section deviated slightly from those defined in *Section 6.0* above due to the way in which the *REED* instrument worked. These procedures were all different by design in order to induce more randomness into our methods to prove that the correlation observed between heat and distance was not influenced by any experimental patterns. The distance between the iPhone and the *REED* instrument did not change throughout each individual test, but did vary between 200 mm and 650 mm in order to introduce more randomness into the testing procedure.

More information on the *REED BX-500 Blackbody Infrared Calibrator* may be found at the following link.

Link: *https://www.reedinstruments.com/product/reed-instruments-bx-500-infrared-temperature-calibrator*

Trial I

All five clusters of infrared dots were analyzed for this trial. Again, each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the dark blue line, and five of the regions accumulated from the TrueDepth camera field of view are defined by *cluster_#.*

The heating procedure followed may be seen below. Two full minutes of data were acquired with the *REED* instrument at 105.4°F before quickly heating up to 134.3°F.

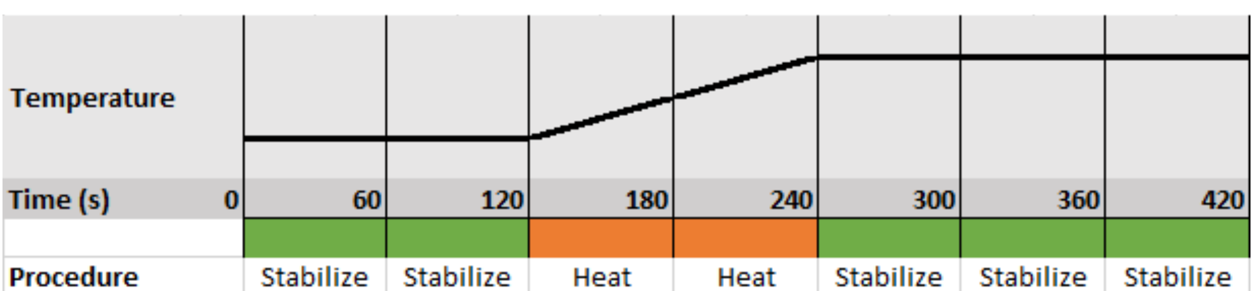


Figure 16 - A reference to the heating and cooling procedure used for this test.

Acquired data for this test may be seen below.

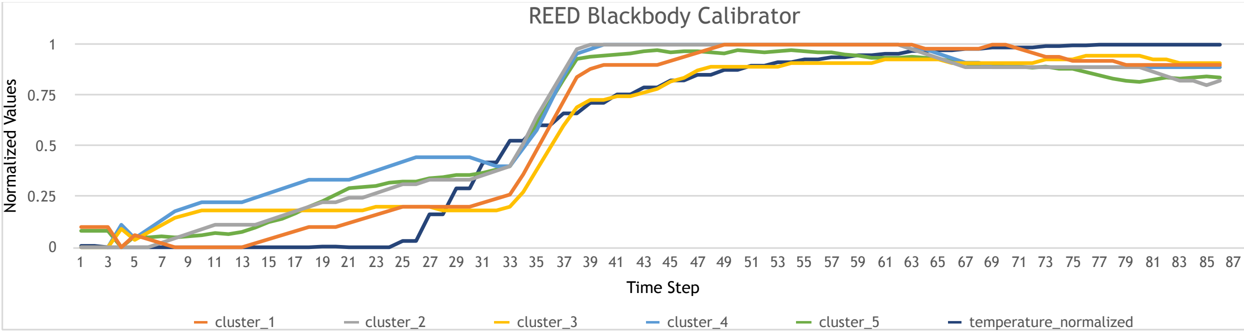


Figure 17 - Results of distance values returned from the TrueDepth camera and temperature values measured on the REED BX-500 instrument. All 5 clusters are shown.

Table 2 shows the correlation for each cluster number compared against temperature. All 5 clusters showed a strong positive correlation with the *REED* instrument's change in temperature. As the temperature rapidly increases around time step 24, so does the response in all five clusters of the TrueDepth camera infrared beams.

Table 2 - Correlation values for each cluster of infrared beams from the TrueDepth camera field of regard are listed below. The correlation values specify the relationship between the change in temperature of the object being measured (the REED BX-500 black body) and the change in returned distance observed by the TrueDepth camera time-of-flight sensor.

Cluster #	Correlation
Cluster 1	97.40%
Cluster 2	94.87%
Cluster 3	97.01%
Cluster 4	93.80%
Cluster 5	95.33%

Trial II

Two of the five clusters of infrared dots were analyzed for this trial. Again, each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the dark blue line, and two of the regions accumulated from the TrueDepth camera field of view are defined by *cluster_#.*

The cooling procedure followed may be seen below. Two full minutes of data were acquired with the *REED* instrument at 130.1°F before quickly cooling to 95.6°F.

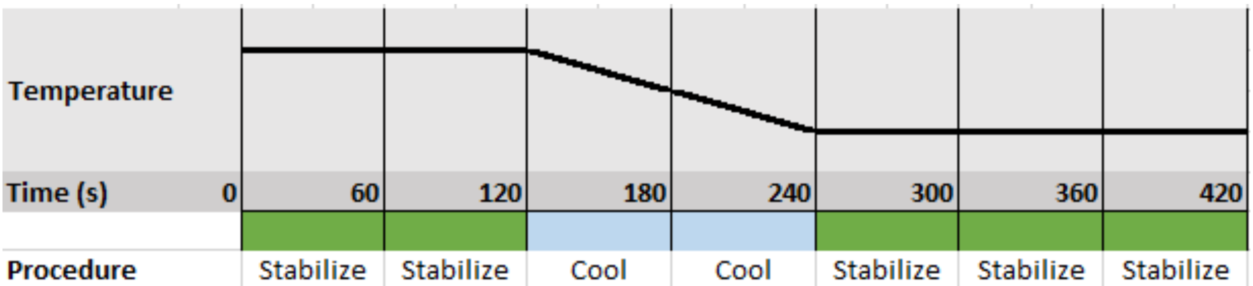


Figure 18 - A reference to the heating and cooling procedure used for this test.

Acquired data for this test may be seen below.

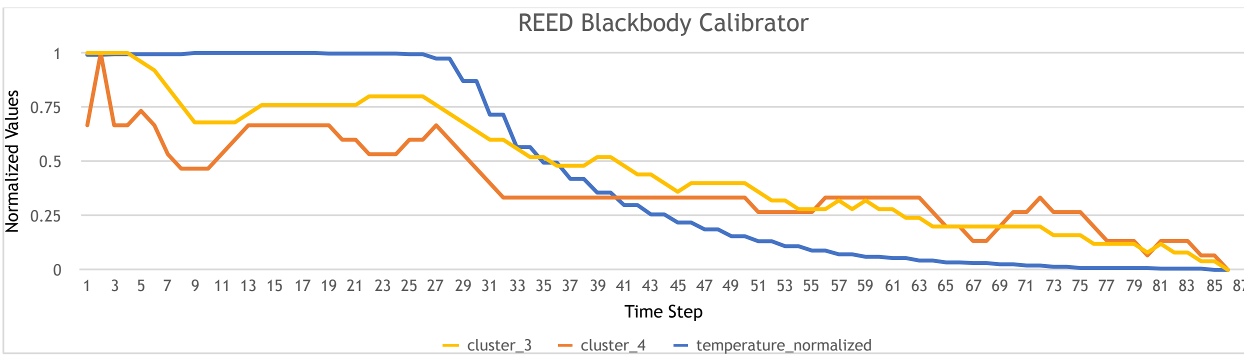


Figure 19 - Results of distance values returned from the TrueDepth camera and temperature values measured on the REED BX-500 instrument. Clusters 3 and 4 are shown.

A 95.29% correlation value was observed for *cluster_3* while an 89.03% correlation value was observed for *cluster_4.* One can see that stability is largely maintained until time step 24 in which the *REED* instrument was instructed to cool down from 130.1°F to 95.6°F.

<u>Trial III</u>

Only one of the five clusters of infrared dots was analyzed for this trial. Again, each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the grey line, and the region accumulated from the TrueDepth camera field of view are defined by *cluster_4.*

The heating procedure followed may be seen below. Seven full minutes of data were acquired with the *REED* instrument beginning at 110.1°F and gradually, uniformly heating to 131.9°F.

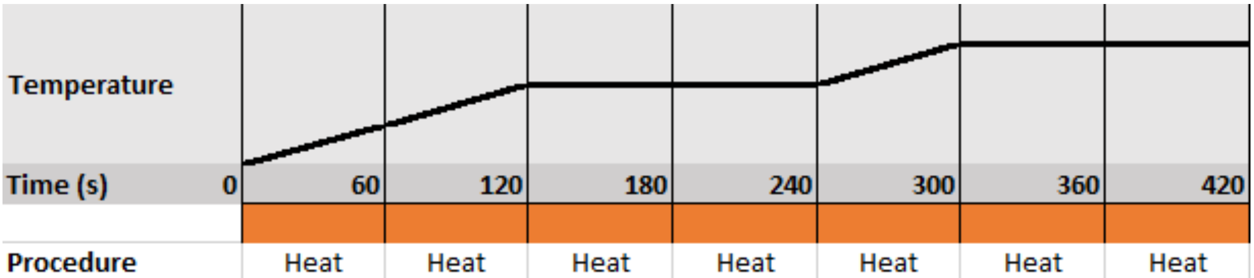


Figure 20 - A reference to the heating and cooling procedure used for this test.

Acquired data for this test may be seen below.

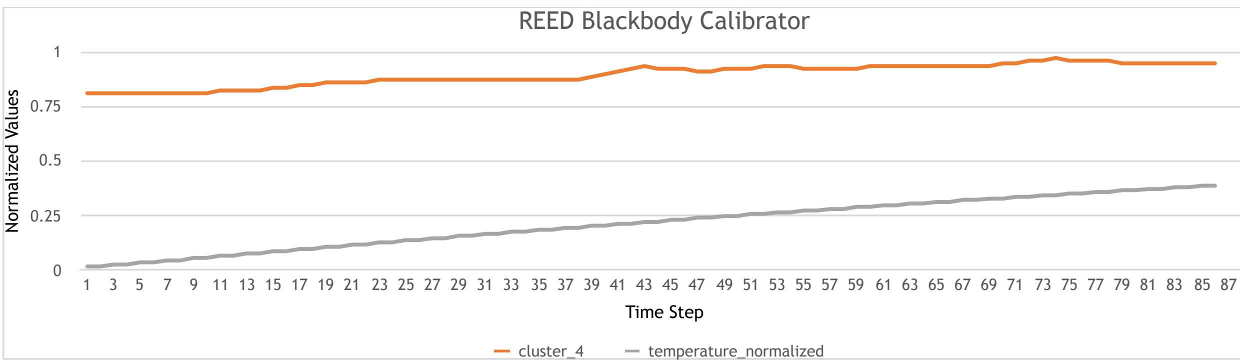


Figure 21 - Results of distance values returned from the TrueDepth camera and temperature values measured on the REED BX-500 instrument. Only cluster 4 is shown.

A 96.99% correlation value was observed for *cluster_4.* One can see that the returned distance from the TrueDepth camera gradually increases as the temperature of the *REED* instrument begins at 110.1°F and gradually, uniformly heats to 131.9°F.

Trial IV

Only one of the five clusters of infrared dots was analyzed for this trial. This time, an extended test was performed for 14 full minutes. Again, each point along the x-axis represents a separate five-second interval in time but this time the range of the x-axis encompasses an 840-second measurement duration. Temperature values are represented by the grey line, and the region accumulated from the TrueDepth camera field of view are defined by *cluster_4.*

The heating and cooling procedure followed may be seen below. Seven full minutes of data were acquired with the *REED* instrument beginning at 99.6°F, rapidly cooling to 99.1°F, rapidly heating up to 109.2°F, and gradually cooling to 96.2°F.

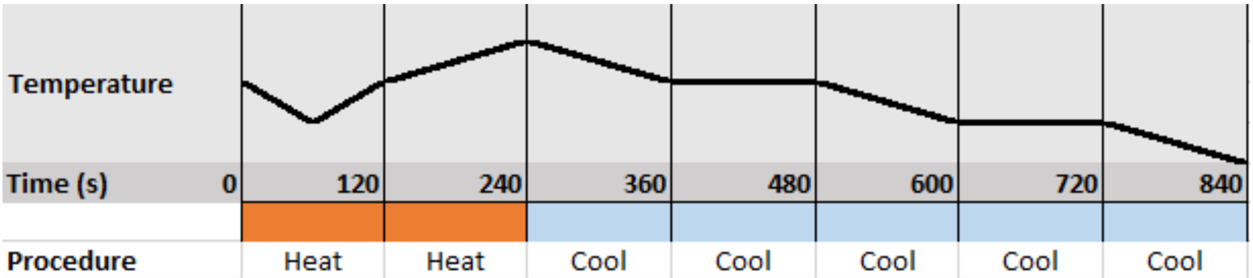


Figure 22 - A reference to the heating and cooling procedure used for this test.

Acquired data for this test may be seen below.

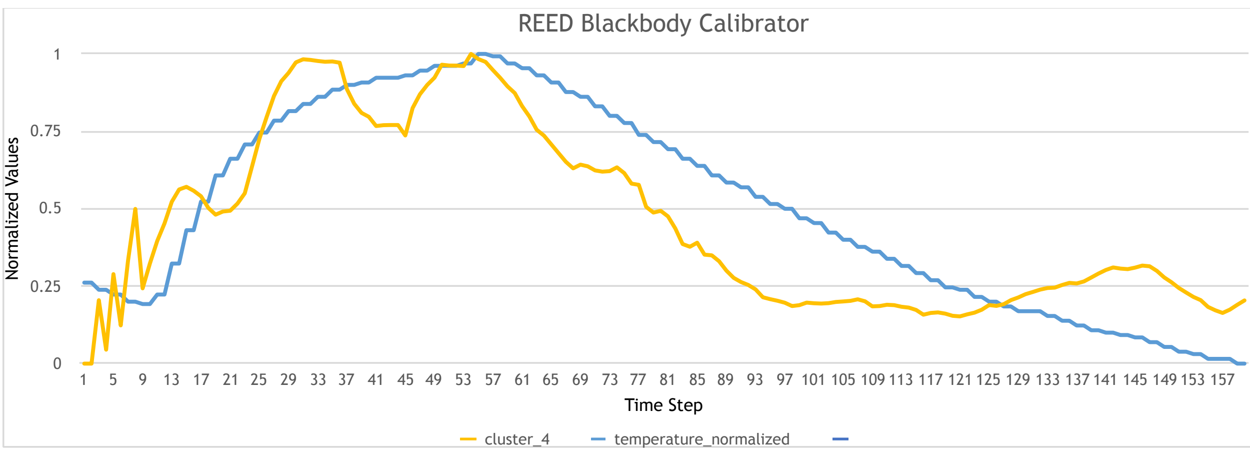


Figure 23 - Results of distance values returned from the TrueDepth camera and temperature values measured on the REED BX-500 instrument. Only cluster 4 is shown.

An 81.86% correlation value was observed for *cluster_4.* One can see that the returned distance from the TrueDepth camera gradually increases as the temperature of the *REED* instrument begins beginning at 99.6°F, rapidly cooling to 99.1°F, rapidly heating up to 109.2°F, and gradually cooling to 96.2°F.

Trial V

Only one of the five clusters of infrared dots was analyzed for this trial. Again, each point along the x-axis represents a separate five-second interval in time along the 420-second measurement duration. Temperature values are represented by the grey line, and the region accumulated from the TrueDepth camera field of view are defined by *cluster_4.*

The heating procedure followed may be seen below. Seven full minutes of data were acquired with the *REED* instrument beginning at 116.6°F and gradually heating to 130.3°F.

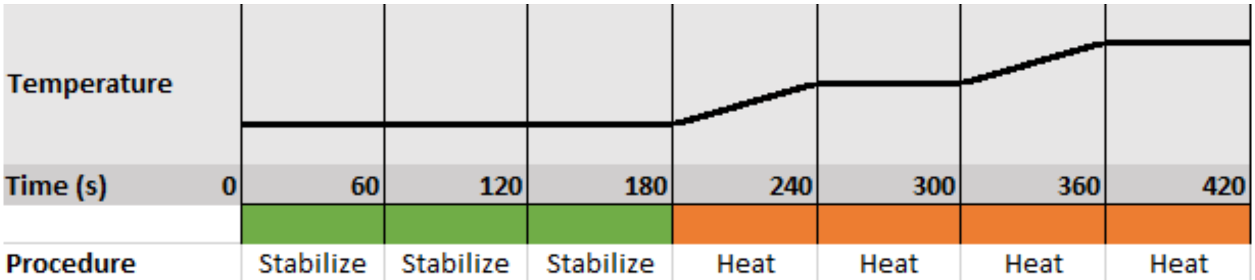


Figure 24 - A reference to the heating and cooling procedure used for this test.

Acquired data for this test may be seen below.

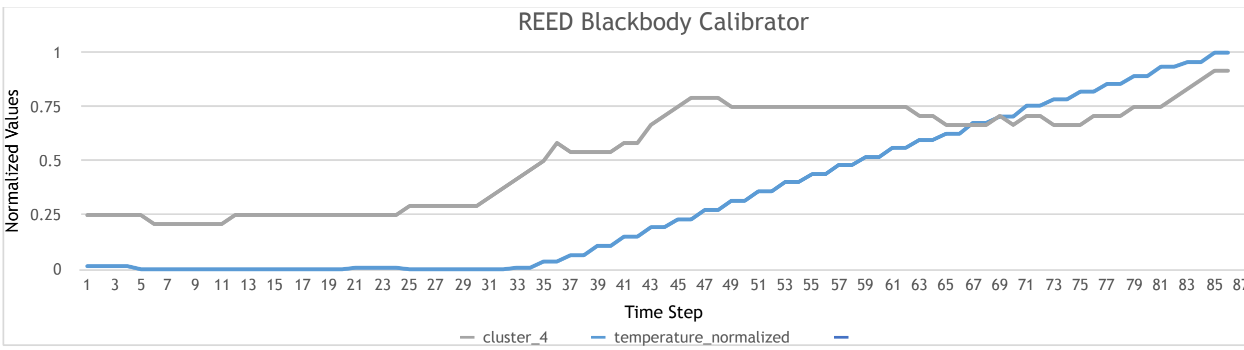


Figure 25 - Results of distance values returned from the TrueDepth camera and temperature values measured on the REED BX-500 instrument. Only cluster 4 is shown.

A 77.98% correlation value was observed for *cluster_4.* One can see that the returned distance from the TrueDepth camera gradually increases as the temperature of the *REED* instrument begins at 116.6°F and gradually heating to 130.3°F.

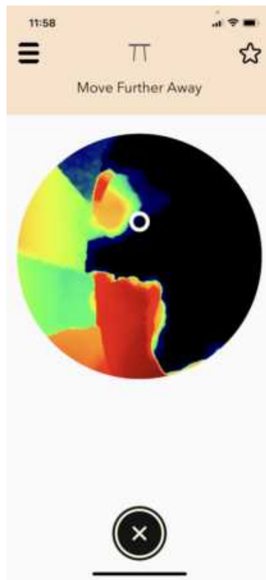
9.0 Conclusion

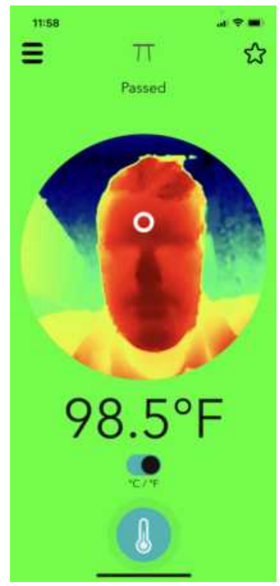
The above experiment confirmed our initial hypothesis – *for any object within the optical field of view at a fixed distance, the Apple TrueDepth camera returns different depth measurements for that object as that object's temperature fluctuates.* This effectively allows the TrueDepth camera to measure temperature on surfaces of known emissivity. Three different materials were observed and several additional trials were validated against an infrared thermometer calibration instrument that is standard for the industry. Randomness was introduced into the experiment to ensure observed statistics were not convoluted by lurking variables or physical phenomenon. In light of the above, very high correlation values were repeatedly observed.

As the tests were repeated several times over for different materials, heating/cooling patterns, and durations, even more confidence grew in the Seekar team that the relationship between depth and temperature could be characterized to allow the TrueDepth camera to accurately measure temperature. Some of the data proved very noisy, and so the software team was responsible for ensuring that noise filtering algorithms were incorporated into the iOS app for further use.

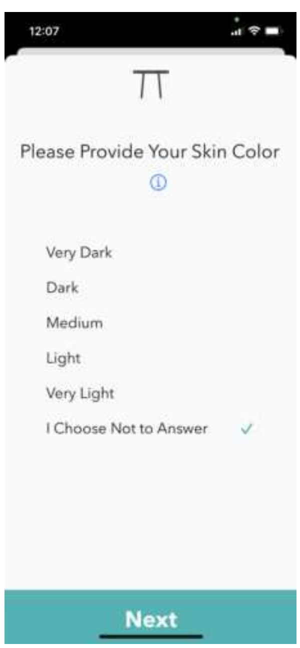
10.0 Additional Verifications

1. Face detection (NOT facial recognition), and a cleaner user interface. The user is guided through on-screen prompts ("come closer", "move further away") to place the phone about 19.0 centimeters away from their face.

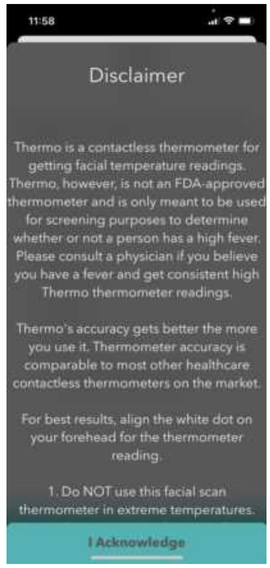




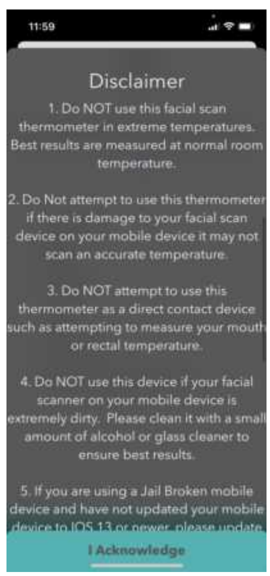
2. Option to input the user's skin color is incorporated into the published app since different colors of skin absorb slightly more or less infrared energy than others.



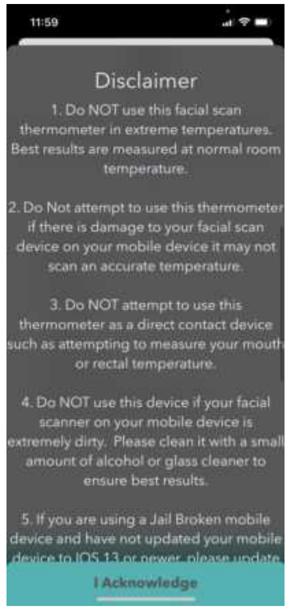
3. Disclaimer stating that the application is not FDA approved.



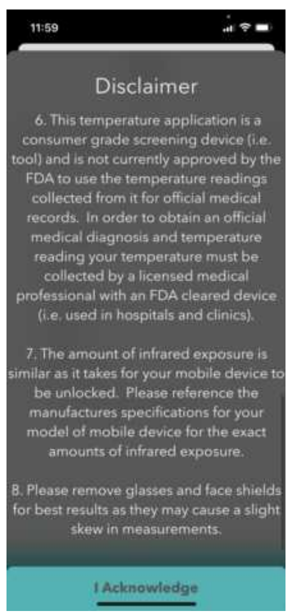
4. Disclaimer that states application is not intended for measuring mouth or rectal temperature.



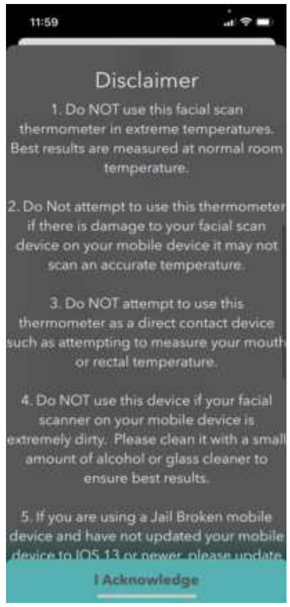
5. Disclaimer that states the application is contactless.



6. Disclaimer indicating that eyeglasses and face shield shall be removed before use.



7. Disclaimer stating operating system requirements should be iOS 13 or newer.


11:59
Disclaimer
1. Do NOT use this facial scan thermometer in extreme temperatures. Best results are measured at normal room temperature.
2. Do Not attempt to use this thermometer if there is damage to your facial scan device on your mobile device it may not scan an accurate temperature.
3. Do NOT attempt to use this thermometer as a direct contact device such as attempting to measure your mouth or rectal temperature.
4. Do NOT use this device if your facial scanner on your mobile device is extremely dirty. Please clean it with a small amount of alcohol or glass cleaner to ensure best results.
5. If you are using a Jail Broken mobile device and have not updated your mobile
I Acknowledge

11.0 References

1) Steiger, O., Felder, J., & Weiss, S. (2008). Calibration of time-of-flight range imaging cameras. *2008 15th IEEE International Conference on Image Processing*, 1-4. https://doi.org/10.1109/icip.2008.4712168

2) Foix, S., Alenya, G., & Torras, C. (2011). Lock-in Time-of-Flight (ToF) Cameras: A Survey. *IEEE Sensors Journal*, *11*(9), 1917-1926. https://doi.org/10.1109/jsen.2010.2101060

3) Hecht, E. (2002). *Optics*. Addison-Wesley.

4) Technical Datasheet, REED BX-500 (2020). Reed Instruments. Web. URL: https://www.reedinstruments.com/product/reed-instruments-bx-500-infrared-temperature-calibrator

5) (2018, April 16). K172889 Trade/Device Name: Infrared Thermometer Regulation Number: 21 CFR 880.2910 Regulation Name: Clinical Electronic Thermometer Regulatory Class: Class II Product Code: FLL Dated: April 16, 2018 Received: April 16, 2018. *This is an email from the United States Food and Drug Administration granting 510(k) approval for the PC868 infrared thermometer instrument used in this experiment. URL: https://www.accessdata.fda.gov/cdrh_docs/pdf17/K172889.pdf*