Thermal imaging method in the evaluation of obesity in various body regions – A preliminary study

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Abstract. Technologies like 3-dimensional scanners and thermal imaging are slowly overtaking the traditional means of evaluating the obesity. The purpose of this study was to evaluate the mean skin surface temperature of different regions such as abdominal, shank, gluteal (thigh), forearm, neck, fingerbed region and to study the potential of feature extracted from thermograph of various region and its measured skin temperature values in the evaluation of obesity. In this preliminary study 30 normal and 30 obese young adult of age 19-23 years were invited out of which 30 were female and 30 were male. Thermal imaging of abdominal, shank, gluteal, forearm, neck and fingerbed regions was acquired and average skin temperature was estimated in various regions for obese and normal subjects. Among the six region studied, neck region shows the greater temperature variation between the study population. In total population studied, the feature extracted parameter depicted positive association with mean skin surface temperature in various regions. Among various feature extracted parameters, mean and total standard deviation depicted the highest significance in abdomen (mean- r = 0.877, TSD- r = 0.449), neck (mean- r = 0.910, TSD- r = -0.617) and in forearm region (mean- r = 0.918, TSD- r = -0.404). ANOVA test provided a significant difference between the skin surface temperature of the groups (normal and obese subjects) at abdomen [F (1, 58) = 261.265, p< 0.05], forearm [F (1, 58) = 619.586, p< 0.05] and neck region [F (1, 58) = 492.322, p< 0.05]. Feed Forward Back Propagation Neural Network provided 98% accuracy, 95% sensitivity and 92% specificity while classifying normal and obese subjects.

1. Introduction
Obesity is one of the most underestimated problems in the community or public health related field [1]. It is an abnormal accumulation of fat in the human body which can later leads to many serious health conditions [2]. It is linked with various comorbidities such as cardiovascular diseases, obstructive sleep apnea, type II diabetes, degenerative joint disease, pseudotumor cerebri, metabolic syndrome, venous statis disease, polycystic ovarian syndrome etc. [3]. In 2016, the prevalence of cases of obesity recorded globally was 13% [4]. In India, the prevalence of obesity in male and female is 9.3% and 12.6% respectively [5].

There are various examination techniques available for the assessment of obesity. Some of them are Anthropometric method which includes body mass index (BMI), waist and hip circumference and skin fold thickness, Bioelectrical impedance analysis (BIA), Ultrasound technique, Dual X-ray absorptiometry (DEXA), Computed tomography (CT), Magnetic resonance imaging (MRI), Thermal imaging etc. [6]. These newer techniques has an advantage of non invasive and is computerized that makes the data collection rapid [7]. Thermal camera is used in the measurement of thermal energy.
emitted by the region of interest with the help of infrared imaging [8]. Sangamithirai et.al. estimated the temperature differences in various body parts in normal and obese individuals [9]. Savastano et.al. investigated the association between the abdominal and fingersbed temperature difference in normal and obese subjects [10]. Bushra et.al. studied the role of heat dissipation alteration in obese and normal women and generated the temperature mapping of the skin temperature for abdomen and in fingerbed region [11]. Roschelle et.al. evaluated the relationship between the thermal imaging and waist circumference (WC) in normal and obese subjects [12]. Hartwig et.al. identified and monitored temperature variation associated to brown adipose tissue in adults with varying BMI [13]. Ana et.al. studied and indicated that skin temperature distribution is determined by the volume of fat accumulated at each body segment [14]. Thus, the purpose of this study was to measure the average temperature in various body regions such as abdominal, shank, gluteal, forearm, neck and fingerbed region, to extract the statistical features from required region of interest in thermal images of normal and obese subjects and to study the classification using artificial neural network.

2. Methodology

2.1. Participant
This study was conducted on sixty healthy normal and obese subjects, age ranging from 19 to 24 years (20.7±1.42) out of which thirty were men and thirty were female. The approval for this study was granted by the ethical committee of SRM hospital. None of the participant of this study was under medication that would have affected the heat balance in their body. Also prior to the study, the participant were asked to read and sign in the consent form.

2.2. Experimental setup
The temperature of the study room where the thermal imaging will be acquired was maintained at 21°C and the participant were asked to wear the comfortable light clothes. Firstly, the participants were asked to stand on the digital scales to measure the weight. The height was recorded with the help of physical height scale. Then with the help of height and weight, the BMI was calculated and recorded for each subject. A table was set up and the thermal camera was placed at one end of the table and the participants were asked to stand at the other end for the measurement to be carried out. The focal length of the thermal camera was maintained at 600 mm. Secondly, the participants were asked to stand in a supine position and expose the abdominal, shank, gluteal, forearm, neck and fingerbed region for acquiring the thermal image of these regions for the study.

2.3. Regional body temperature measurement
The thermal camera used for the study has 640*512 array of sensor for detecting even a minute changes in the temperature. The thermal images obtained from the various region of interest were stored in a computer for the further analysis. During the thermal imaging data collection session, the participants were asked to stay still to avoid any possible movement artefact. The images were analyzed using FLIR Thermal camera (FLIR A325sc, FLIR Systems, Inc., Wilsonville, Oregon, U.S).

During the abdominal region imaging, the participants were asked to raise the clothing in such a way that the whole abdominal region was exposed. Exposure region was maintained from the xiphoid process to 2.24 cm above the symphysis pubis in each participant. Next for the shank region, participants were asked to adjust the clothing in order to expose the entire shank region and the thermal images were collected. Then the participants were asked to expose with no clothing on gluteal, forearm and neck region. The thermal image of each region was recorded for both normal and obese subjects. Finally the participants were asked to rest their hands on the table and expose the palm region for the thermal imaging from which temperature pattern of finger bed is recorded.

The collected thermal images of various region of interest were processed using FLIR tools (FLIR Tools, FLIR Systems, Inc., Wilsonville, Oregon, U.S). Then the temperature values were obtained for each region by placing the rectangular ROI of 1.2 cm in the particular place. For abdomen area, region
just below the belly button was selected. For regions like shank, gluteal, forearm and neck, the rectangular ROI was placed at the centre of each region in all the images. Then for fingerbed region, any one finger is selected and the rectangular ROI is placed at the top. These ROI was maintained same for each image of various regions for measuring the temperature pattern in each region.

2.4. Feature extraction
The features were extracted from various regions such as abdominal, shank, gluteal, forearm and neck using MATLAB (MATLAB R2015, MathWorks, California) software. The various features extracted were mean, total Variance (TV), total Standard Variation (TSV), entropy, contrast, correlation, energy and homogeneity. Mean returns the average of its arguments. TV is the measure of complementary of an image based on its spatial variation. TSV estimates the standard deviation based on a sample. Entropy in an image processing is a measurement of information content in an image. It is a corresponding state of intensity level which the individual pixel can adapt. Contrast is the difference in luminance that makes an object in an image distinguishable. Correlation is multiplying each pixel in the template by the image pixel and then summing of the results to obtain the value of correlation. Energy captures the solution that is required and performs gradient descent in order to obtain the result for image segmentation. Homogeneity is the uniformity of several elements and calculates the similarity between all of them.

2.5. Feed forward back propagation neural network (FFBPNN)
FFBPNN is an artificial neural network comprising of an input layer, hidden layers and an output layer. While training the network, calculations are performed in the input layer. During the training process, the network linearly proceeds to the output layer without processing the loop. The error value obtained after completing training at each layer is back propagated to the previous layers to obtain the desired output. The feature extracted data from abdomen, forearm and neck region for normal and obese subjects is fed as an input for the FFBPNN using NPR tools in MATLAB. Out of 100% input data, 70% data is deployed for training the network, 15% of data is used for validation and the remaining 15% is used for testing the network.

3. Result and discussion
The average temperature was measured by means of fixed ROI (1x1cm) in various regions such as abdomen, fingerbed, forearm, neck, shank and gluteal region for the total population studied. Figure 1a and 1b represents the temperature evaluated at abdominal region of normal and obese subject respectively. The mean temperature obtained at abdominal region of all normal and obese subjects is 34.24 ± 0.23 °C and 32.04 ± 0.49 °C respectively as represented in table 1. Figure 2a and 2b specify the temperature calculated at fingerbed of normal and an obese subject respectively. The mean temperature acquired at fingerbed region of all normal and obese subjects is 31.78 ± 0.76 °C and 33.38 ± 0.86 °C respectively (table1). Figure 3 represents the temperature computed at forearm region of normal (3a) and obese (3b) subject. The mean temperature derived at forearm region of normal and obese subject is 34.91±0.43 °C and 32.21±0.62 °C respectively (table1). Figure 4a and 4b represents the temperature estimated at clavicle / neck region of normal (36.31±0.81°C) and obese (32.96±1.27°C) subject respectively given in table 1. Figure 5a and 5b depicts the temperature assessed at shank region of normal and obese subject respectively. The mean average temperature measured were 33.82±0.61°C for normal and 32.18±0.72°C for obese subject. Figure 6a and 6b illustrate the temperature evaluated at gluteal region of normal (32.54±0.66°C) and obese (33.26±1.06°C) subject respectively. Table 2 summarises the temperature difference between normal and obese subjects. This temperature difference exists in order to maintain the normothermia or normal body temperature in a human body.
Figure 1. Thermal imaging of an abdominal region and evaluation of average temperature of a (a) normal and an (b) obese subject.

Figure 2. Thermal imaging of a fingerbed region and evaluation of average temperature of a (a) normal and an (b) obese subject.

Figure 3. Thermal imaging of a forearm region and evaluation of average temperature of a (a) normal and an (b) obese subject.
Figure 4. Thermal imaging of a neck region and evaluation of average temperature of a (a) normal and an (b) obese subject.

Figure 5. Thermal imaging of a shank region and evaluation of average temperature of a (a) normal and an (b) obese subject.

Figure 6. Thermal imaging of a gluteal region and evaluation of average temperature of a (a) normal and an (b) obese subject.
Figure 7. Training, validation, testing and all ROC (Receiver operating characteristic) obtained by performing FFBPNN for normal and obese subjects.

| Region  | Abdomen | Finger | Forearm | Neck     | Shank    | Gluteal |
|---------|---------|--------|---------|----------|----------|---------|
| Normal  | 34.24±0.23 | 31.78±0.76 | 34.91±0.43 | 36.31±0.81 | 33.82±0.61 | 32.54±0.66 |
| Obese   | 32.04±0.49 | 33.38±0.86 | 32.21±0.62 | 32.96±1.27 | 32.18±0.72 | 33.26±1.06 |
| % difference | 6.42 | -5.03 | 7.73 | 9.21 | 4.85 | -2.21 |

Table 2. Variation of temperature (°C) in various regions in normal and obese subject.

| Region  | Normal (Temperature) | Obese (Temperature) |
|---------|----------------------|----------------------|
| Abdomen | More                 | Less                 |
| Finger  | Less                 | More                 |
| Forearm | More                 | Less                 |
| Neck    | More                 | Less                 |
| Shank   | More                 | Less                 |
| Thigh   | Less                 | More                 |
Table 3. Feature extracted in finger bed region for normal and obese subjects.

| Parameters            | Finger Normal | Finger Obese | Percentage difference |
|-----------------------|---------------|--------------|-----------------------|
| Mean                  | 118.283±20.279| 156.049±10.133| -31.929               |
| Total Variance        | 50.608±11.728 | 45.274±11.535 | 10.539                |
| Total Standard Variation| 6.308±2.056  | 6.335±1.181   | -0.431                |
| Entropy               | 4.623±0.785   | 4.661±0.529   | -0.812                |
| Contrast              | 0.166±0.123   | 0.129±0.054   | 22.187                |
| Correlation           | 0.530±0.095   | 0.629±0.143   | -18.692               |
| Energy                | 0.571±0.282   | 0.587±0.221   | -2.832                |
| Homogenity            | 0.916±0.061   | 0.935±0.027   | -2.022                |

Table 4. Feature extracted in shank region for normal and obese subjects.

| Parameters            | Shank Normal | Shank Obese | Percentage difference |
|-----------------------|--------------|-------------|-----------------------|
| Mean                  | 151.051±20.526| 149.059±16.376 | 1.318               |
| Total Variance        | 25.636±6.828 | 39.408±2.749 | -53.717               |
| Total Standard Variation| 4.447±1.524 | 6.711±1.682 | -50.903               |
| Entropy               | 4.464±0.614  | 5.230±0.775  | -17.161               |
| Contrast              | 0.022±0.016  | 0.045±0.018  | -105.248              |
| Correlation           | 0.740±0.188  | 0.850±0.174  | -14.935               |
| Energy                | 0.840±0.143  | 0.620±0.212  | 26.181                |
| Homogenity            | 0.988±0.008  | 0.980±0.012  | 0.871                 |

Table 5. Feature extracted in thigh region for normal and obese subjects.

| Parameters            | Thigh Normal | Thigh Obese | Percentage difference |
|-----------------------|--------------|-------------|-----------------------|
| Mean                  | 126.601±19.546 | 172.130±18.515 | -35.962               |
| Total Variance        | 57.715±17.099 | 67.008±13.683 | -16.102               |
| Total Standard Variation| 7.378±1.302 | 7.903±1.128  | -7.109                |
| Entropy               | 5.427±0.433  | 5.639±0.471  | -3.907                |
| Contrast              | 0.623±0.195  | 0.543±0.202  | 12.792                |
| Correlation           | 0.895±0.025  | 0.878±0.088  | 1.874                 |
| Energy                | 0.038±0.019  | 0.037±0.013  | 3.977                 |
| Homogenity            | 0.980±0.009  | 0.981±0.006  | -0.081                |
Table 6. Feature extracted in neck region for normal and obese subjects.

| Parameters                  | Normal               | Obese                | Percentage difference |
|-----------------------------|----------------------|----------------------|-----------------------|
| Mean                        | 218.175±20.714       | 149.317±20.181       | 31.561                |
| Total Variance              | 24.785±2.868         | 53.960±9.291         | -117.714              |
| Total Standard Variation    | 4.439±1.158          | 7.232±1.437          | -62.903               |
| Entropy                     | 4.335±0.986          | 5.398±0.272          | -24.519               |
| Contrast                    | 0.032±0.020          | 0.039±0.007          | -23.389               |
| Correlation                 | 0.789±0.190          | 0.922±0.034          | -16.845               |
| Energy                      | 0.826±0.192          | 0.530±0.086          | 35.781                |
| Homogenity                  | 0.989±0.013          | 0.982±0.005          | 0.681                 |

Table 7. Feature extracted in forearm region for normal and obese subjects.

| Parameters                  | Normal               | Obese                | Percentage difference |
|-----------------------------|----------------------|----------------------|-----------------------|
| Mean                        | 160.013±13.996       | 128.868±20.552       | 19.464                |
| Total Variance              | 26.438±5.671         | 42.713±9.708         | -61.561               |
| Total Standard Variation    | 5.277±0.853          | 6.583±1.868          | -24.734               |
| Entropy                     | 4.977±0.247          | 5.214±0.545          | -4.769                |
| Contrast                    | 0.019±0.009          | 0.030±0.009          | -55.842               |
| Correlation                 | 0.927±0.016          | 0.902±0.045          | 2.653                 |
| Energy                      | 0.706±0.147          | 0.713±0.191          | -0.984                |
| Homogenity                  | 0.990±0.004          | 0.987±0.007          | 0.24                  |

Table 8. Feature extracted in abdomen region for normal and obese subjects.

| Parameters                  | Normal               | Obese                | Percentage difference |
|-----------------------------|----------------------|----------------------|-----------------------|
| Mean                        | 157.107±17.883       | 114.254±15.508       | 22.276                |
| Total Variance              | 44.282±15.309        | 48.021±9.620         | -8.443                |
| Total Standard Variation    | 6.077±1.636          | 6.232±1.572          | -2.543                |
| Entropy                     | 5.040±0.637          | 4.921±0.564          | 2.351                 |
| Contrast                    | 0.040±0.014          | 0.036±0.012          | 9.601                 |
| Correlation                 | 0.884±0.050          | 0.919±0.043          | -3.916                |
| Energy                      | 0.632±0.215          | 0.600±0.182          | 5.201                 |
| Homogenity                  | 0.982±0.010          | 0.984±0.008          | -0.197                |
Table 9. Correlation between regional temperature and various feature extracted parameter at abdomen, neck and forearm region.

| Regional Temperature | Mean | Total Variance | Total Deviation | Standard Deviation | Entropy | Contrast | Correlation | Energy | Homogeneity |
|----------------------|------|----------------|-----------------|--------------------|---------|----------|-------------|--------|-------------|
| Abdomen              | 0.87 | 0.274*         | 0.449***        | 0.137              | -       | -        | -           | -      | -0.096*     |
|                      |      | 7**            |                 |                    |         | **       | **          |        |             |
| Neck                 | 0.91 | -0.788**       | -0.617**        | 0.136*             | 0.528   | 0.351**  | 0.428       | 0.463  | 0.239*      |
|                      |      | 0**            |                 |                    |         | **       | **          |        |             |
| Forearm              | 0.91 | -0.646**       | -0.404**        | 0.112*             | -       | 0.673**  | 0.239*      | 0.093  | 0.111*      |
|                      |      | 8**            |                 |                    |         | **       | **          |        |             |

*p<0.05 **p<0.01 † p>0.05

Table 10. ANOVA test for various regional temperatures between normal and obese subjects.

| ANOVA | Sum of Squares | df | Mean Square | F | Significance |
|-------|----------------|----|-------------|---|--------------|
| Abdomen Temperature | Between Groups | 184.1 | 1 | 184.1 | 261.265 | 0 |
| | Within Groups | 40.87 | 58 | 0.705 | | | |
| | Total | 224.97 | 59 | | | | |
| Forearm Temperature | Between Groups | 144.15 | 1 | 144.15 | 619.586 | 0 |
| | Within Groups | 13.494 | 58 | 0.233 | | | |
| | Total | 157.644 | 59 | | | | |
| Neck Temperature | Between Groups | 262.923 | 1 | 262.923 | 492.322 | 0 |
| | Within Groups | 30.975 | 58 | 0.534 | | | |
| | Total | 293.897 | 59 | | | | |

Table 3 depicts the features extracted values of fingerbed region in normal and obese subject. It is found that contrast (22.187) has the most significant difference between normal (0.166±0.123) and obese (0.129±0.054) subject. This is due to the non uniformity in the gray level in normal subject. Table 4 depicts the features extracted values of shank region in normal and obese subject. It is found that energy (26.181) has the most significant difference between normal (0.840±0.143) and obese (0.620±0.212) subject. Table 5 depicts the features extracted values of thigh region in normal and obese subject. It is found that contrast (12.792) has the most significant difference between normal (0.623±0.195) and obese (0.543±0.202) subject. Table 6 depicts the features extracted values of neck region in normal and obese subject. It is found that energy (35.781) has the most significant difference between normal (0.840±0.143) and obese (0.530±0.086) subject. Table 7 depicts the features extracted values of forearm region in normal and obese subject. It is found that mean (19.464) has the most significant difference between normal (160.013±13.996) and obese (128.868±20.552) subject. Table 8 depicts the features extracted values of abdomen region in normal and obese subject. It is found that mean (22.276) has the highest significant difference between normal (157.107±17.883) and obese (114.254±15.508) subject.

The percentage difference of the average intensity (mean) value of the forearm and abdomen was obtained as 19.464 and 22.676 respectively. This correlates with high skin temperature calculated at forearm and abdominal region of normal subject. The contrast parameter in the feature extraction is the intensity contrast between the ROI pixel and its neighbours. Hence, in the case of normal subjects high contrast value was obtained in the regions of fingerbed and gluteal as the temperature in those
regions were found to be significantly lower than that of obese subjects. The textural uniformity that
means pixel par repetition is known as energy in feature extraction. Hence, in the case of normal
subjects, due to the uneven distribution of temperature in neck and shank region, the energy obtained
was higher as compared to obese subjects. This also illustrates a positive correlation with the
significantly high skin temperature obtained in neck and shank region of normal subject.

Sangamithirai et.al. acquired mean skin surface temperature computed at forearm as 33.21±1.6 °C
for normal and 32.31±1.81 °C for obese subjects. Also, for the abdominal region, 33.17±1.03 °C for
normal and 32.86±1.16 °C was obtained for obese subjects. In the thigh region, 32.65±1.37 °C for
normal and 32.61±1.39 °C for obese subjects was obtained [9]. In this current study, we obtained
similar result for forearm (34.91±0.43 °C for normal and 32.21±0.62 °C for obese), abdomen
(34.24±0.23 °C for normal, 32.04±0.49 °C for obese ), and in gluteal region (32.54±0.66 °C for normal
and 33.26±1.06 °C). Savastano et.al. measured the average mean surface temperature of abdominal
region and obtained result for normal and obese subjects as 33±0.3 °C and 31.8±0.3 °C respectively.
Mean skin temperature of fingerbed region in normal and obese subjects was found to be 33.9±0.7 °C
and 28.6±0.9 °C respectively [10]. Similar results were obtained in our study which is given in table 1.
Bushra et.al. evaluated that mean abdominal temperature was significantly greater in normal
(34.11±0.70 °C) than obese subjects (32.92± 1.24 °C). However, mean hand temperature was found to
be greater in obese (31.87±3.06 °C) than normal (28.22±3.11 °C) subjects [11]. In this study, we
obtained similar results, tabulated in table 1. Pearson correlation was performed in total study
population and the correlation values were tabulated in table 9. The Correlation study provides
the relationship between the regional skin temperatures of abdomen, neck and forearm with the various
feature extracted from the thermal images. Among various feature extracted parameters, mean and
total standard deviation depicted the highest significance in abdomen (mean- r = 0.877, TSD- r =
0.449), neck (mean- r = 0.910, TSD- r = -0.617) and in forearm region (mean- r = 0.918, TSD- r = -
0.404). ANOVA test was performed for various regional temperatures between normal and obese
subjects and is tabulated in table 10. There exist a significant difference between the skin surface
temperature of the groups (normal and obese subjects) at regions like abdomen [F (1, 58) = 261.265,
p< 0.05], forearm [F (1, 58) = 619.586, p< 0.05] and neck [F (1, 58) = 492.322, p< 0.05]. FFBPNN
approach provided 98% accuracy, 95% sensitivity and 92% specificity while classifying normal and
obese subjects. The training, validation, testing and all Receiver Operating Characteristic (ROC) graph
is also obtained which is shown in figure 7.

4. Conclusion
In this study, the measured mean average skin temperature of various regions positively correlated
with the extracted feature of the various regions such as abdominal, shank, gluteal, forearm, neck and
fingerbed region. Among the six region studied, neck region shows the greater temperature variation
between the study population followed by abdomen and forearm region. A significant difference
between skin surface temperature of normal and obese subjects was determined by the ANOVA test.
Also, FFBPNN provided good accuracy, sensitivity and specificity while classifying normal and obese
subjects. The limitation of this study includes the small size of the sample analyzed. Also, the manual
selection of ROI on study images of various regions could interrupt the accuracy of the data. As this
was a pilot study, in future, large number of study population can be chosen. Thus by acquiring large
volume of data, machine learning and deep learning algorithm can be applied to obtain better accuracy
in future.

5. References
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