Fever Detection for Dynamic Human Environment Using Sensor Fusion

by

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Abstract:

The objective of this thesis is to present an algorithm for processing infrared images and accomplishing automatic detection and path tracking of moving subjects with fever. The detection is based on two main features: the distinction between the geometry of a human face and other objects in the field of view of the camera and the temperature of the radiating object. These features are used for tracking the identified person with fever. The position of camera with respect to direction of motion the walkers appeared to be critical in this process. Infrared thermography is a remote sensing technique used to measure temperatures based on emitted infrared radiation. This application may be used for fever screening in major public places such as airports and hospitals. For this study, we first look at human body and objects in a line of view with different temperatures that would be higher than the normal human body temperature (37.8C at morning and 38.3C at evening). As a part of the experimental study, two humans with different body temperatures walking a path were subjected to automatic fever detection applied for tracking the detected human with fever. The algorithm consists of image processing to threshold objects based on the temperature and template matching used for fever detection in a dynamic human environment.

Contents

1	Introduction.....	1
1.1	Overview	1
1.2	Research Problem.....	2
1.3	Thesis Objectives	3
1.4	Thesis contributions	3
1.5	Organization of the thesis.....	3
2	Related work and Literature Review	5
2.1	Infrared radiation.....	5
2.1.1	Electromagnetic radiation types.....	5
2.1.2	Ideal solution for screening.....	7
2.2	Temperature regulation of human body	8
2.3	Classification of Thermal imaging systems	8
2.4	Fever screening procedure.....	12
2.5	Thermal scanners accuracy and effective parameters	13
2.6	Infrared thermography effectiveness evaluation in fever screening	15
2.6.1	Software features for fever screening	16
2.7	Modification of infrared thermography efficiency in mass fever screening of moving people	18
2.8	Template matching technique	19
2.8.1	Image based matching technique	19
2.8.2	Feature based matching method.....	20
2.9	Structure and functionality of deformable templates	20
3	Infrared cameras foundation and functionality.....	22
3.1	Radiant flux	22
3.1.1	Wavelength	23
3.1.2	Planck's radiation law	24
3.1.3	Emissivity (ϵ).....	26
3.2	Simulation modelling	28

3.2.1	Models creation.....	28
3.2.2	Sample result of simulation.....	31
3.2.3	Image Thresholding	32
3.3	Worm Track-J.....	33
4	Algorithm for identification and Tracking of subjects with fever.....	34
4.1	Strategy for automatic fever person identification.....	34
4.1.1	Thermal image modification (Thresholding).....	35
4.1.2	Filling the Holes	45
4.2	Detection the objects of interest	46
4.2.1	Selection of the objects	46
4.2.2	Template matching.....	47
4.3	Detected objects tracking	59
5.	Illustration of the algorithm using simulated images	63
5.1	Objects used in simulation for template matching	63
5.1.1	Background of images:	64
5.2	Applying the algorithm on simulated images	65
5.2.1	Step to step of template matching algorithm	66
5.2.2	Boundary area extraction	67
5.2.3	Template matching.....	68
5.3	Illustration of experimental result of applying algorithm continues thermal images	70
5.3.1	Continuous thermal images of a objects	71
5.3.2	Thermal image Thresholding will apply	72
5.3.3	Template matching.....	76
5.3.4	Tracking the path of detected object	78
6	Conclusions and Future work	82
6.1	Overall Conclusions	82
6.2	Future work	83

List of Figures

Figure 2.1: Infrared range and their location in the electromagnetic spectrum. (Reproduced from [15])	6
Figure 2.2: The basic components of the thermal imaging system.	7
Figure 2.3: Thermal images taken by type one Thermal imaging systems using a square shaped Temperature reference source, image on the left shows a person with normal temperature and image on the right is a person with fever [21].	9
Figure 2.4: (a) Thermal image of a fever person taken by type two TIS. (b) Thermal image of a normal person taken by type three TIS with two reference temperatures [21].	10
Figure 2.5: Thermal image of a person taken by type four TIS with core body temperature indication [21].	11
Figure 2.6: Infrared fever screening system setup [20]	12
Figure 2.7: An example of the drift of a thermal imager's temperature readings between self-corrections [19].	13
Figure 2.8: Optotherm thermoscreen system setup used in mass fever screening. It includes infrared camera, display and a CPU [26].	16
Figure 2.9: FLIR thermal imaging setup used in mass fever screening [27].	17
Figure 3.1: Angles and distance between the object and detector (reproduced from [46])	23
Figure 3.2: Spectral radiance curve of black body at temperatures 270K (green), 310K (blue) and 340K (red).	25
Figure 3.3: Spectral radiance curve of a real source with temperature (310K) at two different emissivities.	27
Figure 3.4: Model of spherical coordinate system.	29

Figure 3.5: Model of cylindrical coordinate system.	29
Figure 3.6: A view of simulation process.	30
Figure 3.7: (a) Simulated image of a person with temperature (310K), (b) Simulated image of a person (310K) and a heat source (340K).....	31
Figure 3.8: Showing the intensity of the selected pixels from figure (3-10a) (Blue) and the intensity of the selected pixels from figure (3-10b) (red)	32
Figure 4.1 Flow chart of the fever detection algorithm	34
Figure 4.2 Image of (a) human with normal and higher. Temperature and (b) only one human with high temperature.....	35
Figure 4.3: Co-occurrence matrix [54]	42
Figure 4.4: two infrared images shown after and before image thresholding.	44
Figure 4.5: A binary images before and after hole filling	45
Figure 4.6: algorithm successfully detects all objects in the image.....	47
Figure 4.7: thermal image before and after image thresholding, hole filling and filtering out the small objects.....	48
Figure 4.8: image with several objects and object of interest [71].....	49
Figure 4.9: template made from the object of interest [71]	50
Figure 4.10: example of how template will rotate [71][70].....	51
Figure 4.11: edge dilation	52
Figure 4.12: example of a diamond shape template matching in negative and positive correlation [70][71].....	52
The created template will start searching [70] [71] and get matched to the main image in varied rotations next to find the best match, shown in Figure 4.13.....	53
Figure 4.13: Binary template and main image as input and output will be best score matched.....	53
Figure 4.14 A flowchart of steps of template matching process	55
Figure 4.15: transforming all 1 value pixels to 0 and all 0 to 1.....	60

Figure 4.16: Marking the object for tracking process.....	61
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List of Table

Table 3.1: Parameters used in simulations (temperature and emissivity) for different regions.	31
Table 5.1: Showing the template (red boundary) converged with the contours of objects (a-d), their corresponding converged and ΛE values are also shown [70]..	69
Table 5.2.....	78
Table 5.3.....	80

CHAPTER 1

1 Introduction

1.1 Overview

Fever is a common indicator of many infectious diseases such as SARS [1-2]. This has led to temperature monitoring in at healthcare institutions, public areas and private establishments where crowds are expected [3]. Limited information exists on the accuracy of self-reported fever, which is biased by its subjective nature and reliance on travelers' awareness of fever status and willingness to report [4-5]. Indeed, a clinical trial suggested that traditional thermometry is superior to self-reported fever for identifying patients with seasonal influenza [6].

Infrared thermography is an imaging system utilized for building thermal maps by identifying the infrared radiation transmitted from the surface and by changing it into quantifiable signals [7]. In the field of medicine, infrared thermography is used in many different applications like breast cancer, measuring temperature of human body and brain and neurosurgery [8].

A review of medical applications of infrared thermography can be found in the work of Lahiri [9]. Infrared thermography was also assessed as a means of detecting foot-and-mouth disease virus (FMDV)-infected cattle before and after the development of clinical signs [10]. Thermometry methods in which the human should stand in front the camera without any movement, are time-consuming and require close contact with potentially infectious patients. Since saving the time can be a significant benefit of any improvement in this area, development of an algorithm to perform the thermometry of moving people is of a great importance.

This paper investigates an algorithm to process infrared images and accomplish automatic detection and path tracking of moving subjects with fever. The detection is based on two main features: the distinction between the geometry of a human face and other objects in the field of view of the camera, and the temperature of the radiating object. For tracking the identified person as process with fever, the position of camera with respect to direction of motion appeared to be critical. The proposed approach looks at human body and objects in a line of view with different temperatures that would be higher than the upper limit of the normal human body temperature (37.8C at morning and 38.3C at evening). As a part of the experimental study, two humans with different body temperatures were assumed walking on a path and automatic fever detection was applied first, followed by tracking the detected human with fever. The algorithm consists of image processing to threshold objects based on the temperature and template matching used for fever detection in a dynamic human environment.

1.2 Research Problem

Several studies have been done to improve the exactness of infrared thermography in fever detection by considering the temperature measurement precision and automatic face region recognition. Nevertheless during fever detecting in public places, it is plausible that in field of the camera (thermal images) may be several radiating objects too, whose temperatures is in the range of human fever. This might lead to false detection during automatic fever detection. It is essential to inscribe this issue in order to improve the efficiently and to increase the accuracy of infrared thermography in mass screening of fever detection. The first focus of this thesis is on detecting face regions and discriminating those with fever from other hyperthermic areas within the infrared images and then tracking the travel path of the object of the interest will be possible.

1.3 Thesis Objectives

The main Objectives of this study are the development and testing of an algorithm to solve the following problems:

1. Filtering out the objects with temperatures below the normal human body (37°C) using temperature thresholding and morphological processing.
2. Detecting the face region among all the face and non-face regions in the infrared images using template matching and hypothesis testing.
3. Locating the object of interest by having its travel path and speed.

1.4 Thesis contributions

The following are the main research contributions of this thesis corresponding to the objectives above:

1. An algorithm is developed to detect and track the possible face regions with fever temperatures in infrared images including several face and non-face regions. Algorithm includes temperature thresholding, two possible functions for template matching using gradient descent method, and a decision making process.
2. The algorithm is elucidated by detecting human with fever in simulated thermal images, and in experimental images obtained by an infrared camera.

1.5 Organization of the thesis

Chapter 2 provides background knowledge and information of infrared thermography and its use in fever screening, its limitations and previous works.

Chapter 3 includes a brief review of the theoretical foundations of the functioning principles of infrared cameras and simulation study to reproduce relevant scenarios for the current study.

Chapter 4 presents the algorithm for detecting and tracking the face regions with fever temperature in infrared images; it includes image processing techniques, template matching and applying worm-track study on face region.

Chapter 5 presents results and illustration of the algorithm developed in chapter 4 using simulated and experimental images.

Chapter 6 summarizes the work.

CHAPTER 2

2 Related work and Literature Review

2.1 Infrared radiation

After the infra radiation discovery in the early nineteenth century by Herschel, major technological products dominated by related applications of infra radiation. There are different methods for measuring the radiations lead to the development of infrared systems [11]. FLIR was the first company that commercialized infrared camera in 1975. Since that time infrared cameras have been extensively served in different applications.

2.1.1 Electromagnetic radiation types

All objects, that have finite temperature emit energy, are in the form of electromagnetic radiation, which is arranged according to the wavelength or frequency of the electromagnetic spectrum [12]. Depending on their wavelength, the electromagnetic spectrum can be divided into different regions which are ultraviolet, visible, infrared, and microwave. The Ultraviolet region occupies wavelength range of 0.1-0.4 μm while the visible region occupies wavelength range of 0.4-0.7 μm , which is the range that is detectable by a human eye. The infrared region is bounded by visible and microwave region and occupies nearly wavelength range of 0.7-1000 microns (μm). Because radiation in all heated objects is in the infrared range, the term heat and infrared are often used interchangeably [12]. Infrared spectrum is in turn subdivided into five regions: the shortwave region from 0.7-3 μm , mid wave region from 3-5 μm , long wave region from 8-14 μm , and the Far/Extreme IR from 14-1000 μm [13]. As an example, Infrared cameras for fever

screening work in the range of long wave infrared region [14]. The aforementioned spectral regions are schematized in Figure 2.1[11].

Figure 2.1: Infrared range and their location in the electromagnetic spectrum. (Reproduced from [15])

Thermal imaging devices are combined of optics, detectors and a signal processing unit. Signal processing unit has the function of detecting the emitted thermal energy of the target and the background presented within the field of interest. Thermal imaging devices fulfill thermal maps construction process which can be summarized as follows [16]:

1. The infrared radiations, which are received from the field of view, are collected, filtered spectrally, and concentrated onto a multi-element detector array using an optical lens.
2. Incident radiation heats the detector surface, heated surface of detector affects its material properties such as electrical conductivity, which in turn interprets into variation of the output signal.

3. Signal processing unit received output signal from the detectors and converts it to data for display.
4. Depending on infrared emission intensity, the data produced by the signal processing unit is displayed with different colors. Figure 2.2, shows the basic elements of the thermal imaging system.

Figure 2.2: The basic components of the thermal imaging system.

2.1.2 Ideal solution for screening

Severe acute respiratory syndrome (SARS) incidence has infected 8437 people throughout the world causing death for 813 of them in 2003. SARS is a highly contagious disease made by a virus named corona. SARS cardinal symptom and other flu's is fever which is a pandemic [17] [10] [11]. If fever caused by SARS gets detected early in throng places like airports, hospitals and major public places, its spreading will be prevented or at least slowed down. Accurate results of fever screening can be achieved by invasive methods but these methods are very time-

consuming and also labor-intensive. Moreover, check-in points at airports do have strict time constraints that make this solution impractical to be applied. The ideal device for overcoming this problem should be not only non-invasive but also it should be fast and has minimum labor involved. This suggests infrared thermography [15]. Singapore's defense science and technology agency (DSTA) and Singapore technologies electronics introduced the very first infrared fever screening system in 2003, during SARS outbreak.

2.2 Temperature regulation of human body

Heart and brain blood temperature are usually considered as the core of internal body temperature [20]. Human body moderates body temperature to keep it constant by exchanging heat with the environment using different regulatory systems including radiation, conduction, convection and evaporation. Infrared screening systems use emitted radiation to approximate the temperature. Core body temperature uses human body sites such as rectal, oral ear, auxiliary and skin (in the head and neck region), that are exposed to the atmosphere, as proxies. Because facial skin contains blood vessels close to skin surface and also its tenderness, most fever screening procedures available today assumed facial regions the best candidate for showing the core body temperature [20].

2.3 Classification of Thermal imaging systems

There are four types of thermal imaging systems in hand today for mass fever screening [21]:

1. Thermal imaging system type one

Type one Thermal imaging system consists of a thermal imager and a thermal reference source. In this type of systems, the only temperature indication is the thermal reference source,

which is set at a pre-defined threshold temperature. Type one systems use radiance difference sensing between a body temperature and the thermal reference source as measurement principle. The threshold temperature placed in Temperature reference source is used to classify the screened person as feverous or not.

Figure 2.3 shows some examples of thermal images produced by type one Thermal imaging system.

Figure 2.3: Thermal images taken by type one Thermal imaging systems using a square shaped Temperature reference source, image on the left shows a person with normal temperature and image on the right is a person with fever [21].

2. Thermal imaging system type two:

This type of thermal imaging systems do not use any external temperature reference system. This system indicates the temperature of selected pixel (or group of pixels) within the image. The set constant temperature represents a threshold value [21]. A constant colour scale can be set by the user for a demanded threshold temperature. This means when someone's facial skin temperature is more than the threshold temperature, the defined colour by the user is shown in their facial image and then an alarm signal is produced [21]. Figure 2.4a indicates some examples of thermal images produced by type two Thermal imaging system.

3. Thermal imaging system type three:

Type three systems have same functionality like type one. The only exception is that they have two external temperature reference sources configured with temperatures several degrees apart. Recall that type one has only one temperature reference source. The first step for these terminal imaging systems is calibration with two reference temperature. Then fever screening can be started. The major disadvantage of type three Thermal imaging system is constant change in peripheral conditions. These changes may affect the temperature of the reference sources away from producer's setting and cause a measurement error. Thermal images instances taken by TIS type three is shown in Figure 2.4b.

Figure 2.4: (a) Thermal image of a fever person taken by type two TIS. (b) Thermal image of a normal person taken by type three TIS with two reference temperatures [21].

4. Thermal Imaging System type four:

Type four Thermal imaging systems is also has a similar functioning as the type one, except that in addition to imager and TRS it has a new feature, which is a temporal thermometer. Temporal thermometer is the heart of type four thermal imaging system. This temporal thermometer measures temporal artery (on the side of head). First of all, both the subject temperature and TRS are measured using temporal thermometer at the same time. Then, software packages determine the difference between the temperatures and recognize if the subject is

feverous or not. Example of Thermal image taken by type four Thermal imaging systems is shown in Figure 2.5.

The major disadvantage of these types of systems is that they are time consuming, because they need temperatures measured by both temporal thermometer and thermal imager.

Figure 2.5: Thermal image of a person taken by type four TIS with core body temperature indication [21].

2.4 Fever screening procedure

Figure 2.6: Infrared fever screening system setup [20]

Fever screening process by Thermal imaging system (Type one) is shown in Figure 2.6. In public places such as hospitals and airports, people are asked to pass through a specified direction past the temperature reference source, while an operator monitors the display shown in Figure 2.6. Thermal imager is adjusted to focus only on face regions and the TRS. The CPU processes radiation energy seized by the thermal imager constantly and display it on the monitor. The processor uses a color scale to map the temperature [20]. Usually the displayed colors depict the relative increase of temperature in this sequence: black, blue, green, yellow, and red. The operator observes the display carefully and then decides if the subject needs extra check-up according the percentage and size of the red areas on the face regions.

2.5 Thermal scanners accuracy and effective parameters

Several parameters are involved to guarantee accuracy and statistically effective thermal scanner results [15]. These parameters are thermal drift, minimum detectable temperature difference, non-uniformity, distance effects, error and stability of the temperature reading, spatial resolution, different environmental requirements and subject conditions that should be taken into account [15].

Thermal Drift

This class of problems mostly occurs in type two thermal imagers. The detector in type two systems tends to drift over a very short period of time. So, usual self-correction is required as a compensation for the drift. Drift is defined as the temperature shift during the interval between self-corrections (i.e. variance from the true temperature) [15]. Therefore, keeping thermal drift as low as possible is a primary goal when speaking about type two scanners [22].

Figure 2.7: An example of the drift of a thermal imager's temperature readings between self-corrections [19].

Minimum detectable temperature difference

The lowest change in temperature that a thermal imaging system can detect and depict using a color change is called minimum detectable temperature difference. This feature also demonstrates sensitivity in terms of system capability of distinguishing between two close temperature values [22]. Regular minimum detectable temperature difference values are in range of $0.08^{\circ}\text{C} - 0.7^{\circ}\text{C}$ in current Thermal imaging systems. This is not a good range for fever screening process because for instance a device characterized by system with temperature difference of 0.5°C and a threshold temperature of 37°C , might not be able to detect a fever 37.5°C in a subject.

Threshold temperature stability and calibration

Thermal imaging system employs to threshold temperature as a reference to differentiate a brushed temperature from an average temperature. The temperature threshold should be consistent throughout the operation to guarantee screening accuracy [18]. Temperature threshold location in the target plane must be taken into account in order to determine its stability. Also, thermal imagers should be calibrated according to the threshold temperature before screening process gets started.

All discussed parameters have a substantial affect in the thermal scanning process. By knowing type of thermal imaging system, environmental conditions, camera distance from the subject, these factors influence can be minimized to some extent [15].

2.6 Infrared thermography effectiveness evaluation in fever screening

Initial use of Infrared thermography for fever screening was a failure and it ended up with large number of false detections due to lack of experimental data [19]. Several studies were leaded to IR thermography effectiveness evaluation in fever screening [18] [19] [22] [23]. In particular studies were conducted to find an answer for the flowing:

- Best threshold temperature (to discriminate between feverous and normal person)
- A human body spots whose skin temperature has the best correlation with the core body temperature.

One of the major concerns in fever screening is fixing the threshold temperature (to distinguish between feverous and normal person) for type one Thermal imaging systems. This problem was studied in [19], biostatistics method, regression analysis, and artificial neural network based classification were methods for analyzing the temperature data obtained under controlled environmental conditions. Accuracy rate of 96% for identifying with 96% sensitivity and 85.6% specificity by setting threshold temperature to 36.2°C [19]. However, these analysis were performed on only one subject at a time and under controlled environmental conditions.

Best human body spot at which the skin temperature correlates with the core body temperature the best was studied in [18]. Temperature data procured from the face region considering different distances of camera and the subject under controlled environmental conditions was compared with the temperature data gained by conventional thermometers. According to these data, the Infrared thermography readings from sides of face particularly from ear at 0.5m yielded most reputable, accurate and consistent estimates of conventionally determined body temperatures [18].

2.6.1 Software features for fever screening

As discussed in section (2.4), thermal imaging systems assign pseudo colors to objects in the image based on their temperatures [15]. This procedure is either done within a camera or may be sent out to an online or offline computer [24]. Some of available fever screening infrared cameras such as Infrared fever screening systems, FLIR and Optotherm thermoscreen usually have embedded image processing software [25]. Figure 2.8 presents an Optotherm thermoscreen equipped with a software system for massive fever screening.

Figure 2.8: Optotherm thermoscreen system setup used in mass fever screening. It includes infrared camera, display and a CPU [26,72].

Figure 2.9 demonstrates another fever screening setup used by FLIR A320.

Figure 2.9: FLIR thermal imaging setup used in mass fever screening [27].

The aforementioned pieces of software have the following embedded features:

- A predefined threshold temperature can be set such that body temperatures above that are determined with red patches as depicted in Figure 2.9.
- An alarm sound to warn the operator when temperature violation took place.
- Automatic screening mode that uses audible comments to decrease demand on operators.

However, these approaches need subjects to wait in line for screening and temperature screening should be processed for one person at a time in less than a few seconds under controlled environmental conditions. In the case of mass screening of many moving people there is a possibility of hyperthermic areas occurrence other than faces, leading the operator to an absolute and easy confusion because the human face location and its corresponding temperature is not completely screened [28,72]. Additional analysis to evaluate the applicability of the method and its efficiency are required with respect to disturbance and deflection from ideal conditions, in case of violating from controlled standard conditions.

2.7 Modification of infrared thermography efficiency in mass fever screening of moving people

Improving effectiveness of infrared thermography in mass screening of moving people can be achieved by temperature measurement accuracy and system automation [29]. Automation here means capability of recognizing human faces in infrared images automatically. If the device works in a self-administered way, the impact of the radiating heat sources in fever screening can be fulfilled [29], because position of human faces in infrared images is a vital factor to be addressed for rectifying the infrared thermography performance in mass screening of moving people for SARS recognition.

‘Pixel to temperature’ is the standard procedure in infrared cameras (i.e. higher the temperature, the higher is the pixels intensity). In this case the location of face regions in the infrared images can be determined by some simple image processing techniques such as temperature thresholding (30-42 C) and morphological processing (a method for extracting requested image components) [30][31][28].

Neural networks and supervised learning can be used to identify face regions in infrared images [31]. Input layer for neural networks and input data for supervised classification are fed with averaged temperature data (pixel values) of the face regions and the shape factor values to help them with face regions recognition. Multiclass multi feature fuzzy connectedness and spatial filtering using Gabor and Bessel functions are used to create different segments of the face regions and to acquire the wavelet coefficients in another study [33]. A priori probability

can be produced based on distinct facial regions coefficients and then used for hypothesis examination. Bayesian based hypothesis testing is employed to detect the exact face regions [34].

Automatic face recognition in infrared images for fever screening is investigated using image processing algorithms such as temperature thresholding [28] and using smart biometrics system [29]. Two major concerns of using IR camera for fever screening, which are temperature measurement accuracy and capability of automatic screening are addressed in [28] [29]. Support Vector Machine (SVM) and pattern recognition methods are used to find face regions in infrared images. Manually selected face regions with a scale ratio of 20 by 20 by experts are used as training vectors for SVM methods [29]. A false negative rate (locations that include a face region but not detected) of 3.73% was fulfilled via this method. The experimental conditions of this study did not portray the temperature discrimination between febrile and normal faces entirely and the presence of other hyperthermic.

2.8 Template matching technique

Template matching is a technique in signal processing for matching a template image with small sections of an image [35]. This technique is used very often in many fields such as face recognition [36], biophysical data processing [37], and photogrammetric and remote sensing [38]. Among others, two main algorithms have been designed: feature based matching and image based matching.

2.8.1 Image based matching technique

Image based matching is used mostly when properties of the images are not fully distinct or when the template image content constitutes the matching image [35]. In this case, a

template is scanned over the test image pixel by pixel and correlation between them is calculated at the same time [38]. Final correlation score shows that the template is a match with the test image or not. However, image based matching is not widely used in face recognition because it is time consuming and has a high time complexity [38].

2.8.2 Feature based matching method

In this case, template and test images features such as edges or contours are principle matching criteria to find the best matching location of the template in the test image [47]. The system should be designed in a way that makes it capable of searching a large database of images for objects with resembling traits specified by the user while developing an automatic image extraction system [39]. Yuille, Cohen and Hallian proposed a method [45] to illustrate the target object using a deformable template, which is a template model and a set of certifiable geometric deformations. These geometric deformations display properties of a target based on previous knowledge [40].

2.9 Structure and functionality of deformable templates

Deformable templates consist of a prototype and a set of acceptable deformations that map it to an object that regenerate noticeable features of a target to be matched [41]. The set of deformations is often characterized by an affiliated map. A distant function or a metric measure the matching between the template and the test image [42]. Maximum resemblance between the template and the test image means distance function should have minimum possible value [43]. Deformable templates with affiliated transformations are officially tantamount to deformable

steady modeled within first gradient theory [44]. There are two advantages of taken deformable templates into account for geometric recognition of facial regions [46]:

1. Deformed templates are produced with aforetime knowledge about the feature in the test image to be identified.
2. Deformable templates can be implemented simply to give a compendious description of the feature in test image because they only deal with small number of arguments.

CHAPTER 3

3 Infrared cameras foundation and functionality

This chapter covers a short review of the theoretical infrastructure of infrared cameras functionality and simulation study to regenerate related scenarios for the current study.

3.1 Radiant flux

Electromagnetic waves can transport energy (Q) [J] [45]. This is an important and effective feature of them. Radiant flux (φ) [W] is the title used for the energy per unit time(dQ/dt). As power distribution in terms of area or direction for the radiometric computation is our mainly concern, radiance best qualifies such quantity. Radiance (L) is defined as the power per unit area and per unit solid angle (W/m^2sr) [45].

$$L(\lambda, \theta, \varphi) = \frac{\varphi}{A_s \cos \theta_s \Omega_d \lambda} \quad (3.1)$$

where

$$d\Omega_d = dA_d \cos \theta_d / R^2 \quad (3.2)$$

In equation (3.2) dA_s, dA_d shows differential areas of the source and the detector respectively, θ_s and θ_d are angle between the normal and the connector line between both source and the detector. R is the distance between source and the detector. Figure 3.1 depicts angles θ_s and θ_d and the distance between the source and the detector which is R .

Figure 3.1: Angles and distance between the object and detector (reproduced from [46])

We can find a formula for the radiant flux $d^2\varphi$ by rearranging equation (3.1) and we can get

$$d^2\varphi = \frac{L \cos\theta_s \cos\theta_d dA_s dA_d}{R^2} \quad (3.3)$$

Equation (3.3) gives a formula for the radiant flux that departs the differential surface area by angle θ_s and ends at differential area of detector by angle θ_d . In order to calculate the flux radiating from the entire surface area and arriving at the detector zone, integral should be used for equation (3.3) over the entire range of the source and the detector [72].

$$\varphi = \frac{1}{R^2} \int_{A_s} \int_{A_d} L \cos\theta_s \cos\theta_d dA_s dA_d \quad (3.4)$$

Equation (3.4) shows that received power by the detector from the source depends on only to Cosinus of angles θ_s and θ_d ($\cos\theta_s, \cos\theta_d$) and the squared distance R^2 between source and the detector.

3.1.1 Wavelength

Equation (3.1) shows that the radiance (L) does not depend on wavelength. Considering a specific wavelength for the surface emitted radiance with, equation (3.1) can be written as:

$$L(\lambda, \theta, \varphi) = \frac{\varphi}{A_s \cos \theta_s \Omega_d \lambda} \quad (3.5)$$

3.1.2 Planck's radiation law

Emitted energy distribution can be formulated as a function of wavelength for a known temperature. This is described by Planck's law [11]. The spectral emitted radiance from a black object per unit surface and per unit solid angle is formularized by

$$L_{\lambda,b}(\lambda, T) = \frac{2hc^2}{\lambda^5 [\exp\left(\frac{hc}{\lambda KT}\right) - 1]} \quad (3.6)$$

Where the unit for the black object spectral radiance is given by $(W/m^2 sr \mu m)$, by simplifying constants in the equation (3.6), it can be rewritten as

$$L_{\lambda,b}(\lambda, T) = \frac{c_1}{\lambda^5 [\exp\left(\frac{c_2}{\lambda T}\right) - 1]} \quad (3.7)$$

Figure 3.2 presents Planck's radiation curve for black objects for three distinct temperature values.

Figure 3.2: Spectral radiance curve of black body at temperatures 270K (green), 310K (blue) and 340K (red).

According to equation (3.7), objects with greater temperature values have higher radiance values. Getting integrating over all possible wavelengths in equation (3.7), gives the total existence from a black object, which is given in equation (3.8)

$$L_b = \int_0^{\infty} \frac{c_1}{\lambda^5 [\exp(\frac{c_2}{\lambda T}) - 1]} \quad (3.8)$$

Equations (3.8) is only working for the radiance existence from the black object and but for real sources the aforementioned equations have to be corrected [11]. The correction factor is called the emissivity (ϵ), which is explained shortly in the next section.

3.1.3 Emissivity (ϵ)

Emissivity is a feature of emitting energy for a surface. Emissivity is the ratio of a surface emitted radiation to black object emitted radiation under same temperature, direction and spectral band of interest [46]. Because emitted radiation of a black object is always greater or equal to other surfaces, emissivity can only be within the range of 0.0 to 1.0 [47]. At temperature T and emitting direction of (θ, φ) , the surface directional spectral emissivity is given by [11] [72]

$$\epsilon(T, \theta, \varphi) = \frac{L_{\lambda}(\lambda, T, \theta, \varphi)}{L_{\lambda,b}(\lambda, T)} \quad (3.9)$$

In our case, we supposed that emissivity depends only on the temperature and the spectral existence curve of the black object. The latter factor gives the grey object spectral existence curve when scaled by the emissivity as shown in equation (3.10)

$$L_{\lambda}(\lambda, T) = \epsilon(T) L_{\lambda,b}(\lambda, T) \quad (3.10)$$

We can rewrite equation (3.8) using substitution of the black body spectral radiance to get

$$L_{\lambda}(\lambda, T) = \int_0^{\infty} \epsilon(\lambda, T) \frac{c_1}{\lambda^5 [\exp\left(\frac{c_2}{\lambda T}\right) - 1]} d\lambda \quad (3.11)$$

Figure 3.3 demonstrates spectral radiance curve for a real source when temperature kept constant at 310K for two different emissivity.

Figure 3.3: Spectral radiance curve of a real source with temperature (310K) at two different emissivities.

where the infrared cameras work at wavelength range of 8-12 μm , equation (3.11) was integrated only within the range of 8-12 μm .

Because Infrared cameras work at wavelength in the range 8-12 μm , integral for equation (3.11) should get in this range that gives the following

$$L_{\lambda}(\lambda, T) = \int_8^{12} \varepsilon(\lambda, T) \frac{c_1}{\lambda^5 [\exp(\frac{c_2}{\lambda T}) - 1]} d\lambda \quad (3.12)$$

what is calculated in equation (3.12) is the overall existence from the surface of the source within the camera wavelength interval. Total radiant flux density $\left(\frac{W}{m^2} sr \mu m\right)$ which is landing on the surface of the detector can be obtained by substituting equation (3.12) to (3.4).

$$\varphi = \frac{1}{R^2} \int_{A_s} \int_{A_d} L \cos\theta_s \cos\theta_d dA_s dA_d \int_8^{12} \varepsilon(\lambda, T) \frac{c_1}{\lambda^5 [\exp\left(\frac{c_2}{\lambda T}\right) - 1]} d\lambda \quad (3.13)$$

3.2 Simulation modelling

For better understanding of the interaction between various radiating objects within the image, simulations were performed. Spherical and cylindrical shapes are two major models that were applied in simulations. Creating a model is described in the following sections shortly.

3.2.1 Models creation

Hemispherical shape is the first model. Coordinates of hemispherical shape are defined as: [48]

$$x = r \sin\theta \cos\varphi$$

$$y = r \sin\theta \sin\varphi$$

$$z = r \cos\theta$$

where r is sphere radius, θ is the slope varied from 0 to π and φ is the azimuth angle varied from 0 to π (range $[0, 2\pi]$ gives a complete sphere). Z axis is varied in range $[0, 2]$. Figure 3.4 shows coordinate system of this model.

Figure 3.4: Model of spherical coordinate system.

The next model is a cylinder that should be created. Coordinates of this model are given by

$$x = r \cos \varphi$$

$$y = r \sin \varphi$$

where r is cylinder radius, and φ is the azimuth angle in range $[0, \pi]$ to produce half cylinder, and z is cylinder height. Figure 3.5 demonstrates coordinate system cylindrical model.

Figure 3.5: Model of cylindrical coordinate system.

As observable in Figure 3.6, target surface is segmented into different facets and in simulations every facet emitted radiation is computed. Figure 3.6 presents a view of the radiation landing on the detector surface from every facet normal pointing out.

Figure 3.6: A view of simulation process.

In the above view, θ_1 and θ_2 are angles between the normal to the surfaces of source and detector to the line connecting them. Distance between the source surface and detector surface is displayed by R . Equation (3.14) gives us radiation flux density from the surface with respect to the angles θ_1 and θ_2 [72]

$$\varphi = \frac{1}{R^2} \int_{A_s} \int_{A_d} L \cos\theta_s \cos\theta_d dA_s dA_d \int_8^{12} \varepsilon(\lambda, T) \frac{c_1}{\lambda^5 [\exp(\frac{c_2}{\lambda T}) - 1]} d\lambda \quad (3.14)$$

where, the first expression in equation (3.14) contains the angle between differential area of the detector (dA_d) to the differential area of the source (dA_s) and inverse of the distance between

them (R^2) squared. The second expression contains self-emitted spectral radiance from the source surface, based on their temperatures.

3.2.2 Sample result of simulation

Table 3.1 shows two factors (temperature and emissivity) employed in the simulation:

Region	Temperature	Emissivity
Face	310K	0.97
Face (with fever)	330K	0.97
Body region	310K	0.72 (clothes)
Heat sources	315K-340K	0.93
Reference plate	315K	0.95

Table 3.1: Parameters used in simulations (temperature and emissivity) for different regions[72].

Figure 3.7 displays the radiance image of a subject alone while Figure 3.7b depicts radiance image of a person along with a heat source.

Figure 3.7: (a) Simulated image of a person with temperature (310K), (b) Simulated image of a person (310K) and a heat source (340K)

It is clear in Figure 3.7b, that the assumed face are intensity is altered within a heat source. Pixel intensity plot at chosen areas from face regions (blue line) in Figure 3.7a and Figure 3.7b is drawn in Figure 3.8.

Figure 3.8: Showing the intensity of the selected pixels from figure (3-10a) (Blue) and the intensity of the selected pixels from figure (3-10b) (red)

Obviously in Figure 3.8, the intensity of the pixel areas varies in the presence of other heat sources within the thermal camera view. If color scale only thermo-grams are used without temperature values; Fallacious results would appear in fever screening [16] [72].

3.2.3 Image Thresholding

For this experimental study, several methods for image thresholding can be used, for instance, Huang's fuzzy Thresholding [49], Li's Minimum Cross Entropy thresholding[50], Kapur-Sahoo-Wong (Maximum Entropy) thresholding method [51], Otsu's threshold method [52], triangle method [53] and Shanbhag method [54]. All the methods have been experimented for the first step of image Thresholding, results then compromised to each other and among them

the method of shabhang has the best accuracy in image Thresholding for that range of temperature (infrared images in range of human normal body). So we overcome the problem discussed in pervious sections. Chapter 4 will illustrate that we are able to run automatic fever detection based on infrared images without any heat source with high accuracy. So the results obtained within study are based on the Shanbhag method (1994).

3.3 Worm Track-J

For the tracking part of this study, several scenarios were considered at first and unfortunately results for most of them were a failure. However the results for Worm Track-J [55] were a success. Considering the study [56] which was conducted to tracking the path of traveling of worms helped to track our object of interest, consuming our object as the input for the algorithm and with some few changes in its movement parameters we succeeded to track the path of the face region which obtained after Thresholding and template matching steps. These tracking systems can be divided into two classes: single-object trackers and multi-objects trackers. Mostly, single-objects trackers may remove detailed phenotypic characteristics from objects at a high magnification [57–61] while multi-objects trackers are bounded to extracting movement metrics such as speed and travel path from object at a low magnification [62–66]. The algorithm of Worm-Tracker and applying processing of it on this study is completely explained in chapter 4.

CHAPTER 4

4 Algorithm for identification and Tracking of subjects with fever

4.1 Strategy for automatic fever person identification

This Chapter depicts the layout coordinating strategy created to distinguish face shapes in the infrared pictures and tracking. It incorporates object selection, template matching, and decision making process and tracking objects. A block diagram of the algorithm is shown in Figure 4.1

Figure 4.1 Flow chart of the fever detection algorithm

4.1.1 Thermal image modification (Thresholding)

By adjusting the camera based on the normal human body temperatures, objects with higher temperatures will appear in the image convection as mostly red Figure 4.2 a and isolated in **Error! Reference source not found.** b. First step during object identification in any image is o convert it to binary image (black and white), this steps makes it easy to select the desired objects and to extract their contours [37].

(a)

(b)

Figure 4.2 Image of (a) human with normal and higher. Temperature and (b) only one human with high temperature

ALGORITHM OF THRESHOLDING

In light of sufficiency of grey level distribution in any image that we are doing the process on it, the function of decision making relies on the pixel grey level. Class 1 contain of all pixels which are having grey levels 0 to T and similar to that, class 2 comprise all pixels which are having grey levels T + 1 to N, where T describe as the threshold grey level and N is for the total number of grey levels in the image,

$$\begin{aligned}\mu_1(g) &= \begin{cases} 1 & g \leq T \\ 0 & g > T \end{cases} \\ \mu_2(g) &= \begin{cases} 0 & g \leq T \\ 1 & g > T, \end{cases}\end{aligned}\tag{4.1}$$

$\mu_j(g)$ defined as the membership coefficient of the grey level g w.r.t. class j in the thresholded image. In this way, final image will obtained of transforming of the original image with consisting of two crisp pixels sets and with the membership value 1 or 0 [54].

The purpose is to view the main image as also containing of two sets of pixels but having facial membership values. It means that the original image is viewed as to be created of two fuzzy sets. The pixels memberships (corresponding to a grey level) to a set is a measure of our uncertainty in assigning them to the specific class. Grey levels of both rightmost and the leftmost, for example, plainly would have maximum membership coefficients w.r.t class 1 and class 2 separately and, thus, minimum uncertainty associated in assigning them to their respective class.

This membership coefficient is normalized to 1, like always. The uncertainty confident of categorization associated with a grey level w.r.t a specific class is then defined to be 1 (membership value of the grey level w.r.t that class). The process of thresholding or “defuzzification” involve with allotting a crisp set to the pixels. Subsequently, consolidates a decrease in the uncertainty associated in categorizing the pixels. Subsequently, it will lead to supply the “information” in transforming the original image comprising of two fuzzy sets to the final image comprising of two crisp sets. By noting that the image external gray levels should add little to the evaluation.

To determine the uncertainty degree of categorization of the pixels associated with any gray level, solely by and is equal to its probability occurrence within class 1 or class2. As for the independent of the distance from threshold which is chosen, the gathered information (equal to the priori uncertainty) for step of categorizing the pixels, black pixels will get equal value to obtained grayish category with also the so long as the possibility of existence of both theses gray levels, will assumed to be equal within class 1. This inevitability gives a false representation of the instinctive notion that if the amount of greater amount of assertiveness is greater, it would categorize in assigning class 1 to a black pixel rather than in putting in category of the same class to a gray pixel.

Histogram is so modeled as an adjoin (zero memory) source and for the information gathered in classifying categorizing any gray level is nonaligned of the possibility of existence of the neighboring gray levels in class 1/class 2. Hence, according to this approach, great amount of information is classified and also by specifying the left-most gray level to class 1 and for right=most gray level to class 2.

Besides, for an image with specific histogram, T_1 will select for the threshold selected corresponding to maximum entropy. A theoretical stray shuffling of gray levels on the left of T_1 will drive the final threshold T_2 to $0 < T_2 \leq T_1$ while a collected of a threshold $> T_1$ can lead to result in a superior severance of the modes for the histogram. Besides in [67] which threshold is selected as comparing to maximum information and next will be considering the problem of putting an "optimal" threshold only rely on the gray level distribution. So, it will be assumed exact features in the image so that it is a 'legitimately' globally thresholdable one. For bilevel thresholding problem, list of axioms will be set and then obtain a criterion for the best threshold.

The four base assumption for this hypothesis of Thresholding:

1. Obtained information by setting class 1 (class 2) to pixels with minimum (maximum) gray level in the image is zero.
2. A hypothetical gray level T' is set between the fixed threshold gray level T and $T + 1$ so that a "pixel with this gray level" has membership coefficient of 0.5 of belonging to either class.
3. Gray level set to a class must insinuate the membership coefficient of g belonging to that class ≥ 0.5 . also if gray level g_2 is at a greater distance respecting the threshold T than the gray level g_1 , where g_1 and g_2 are on the same side of the threshold T , for the membership coefficient of g_2 belonging to the corresponding class is greater than that of g_1 and information transported is greater in classifying g_1 than in classifying g_2 •
4. The membership coefficient of a gray level w.r.t. a class rely on and grow up respecting to frequency of existence of the pixels with that gray level. When axioms 1, 2 and 3 are apparent, the logic backing of axiom 4 is to get a higher membership for the pixels with gray levels at

greater distances from the threshold (w.r. t. addresses to the number of pixels with intermediate gray levels) within a certain class. By assuming a linear relationship in axiom (4), from (2) and (4), [54] it will result for the membership of the threshold, $T \in$ class 1 is

$$P_{1,T}(T) = 0.5 + kp(T) \quad (4.2)$$

where $p(T)$ is chance of existence of pixels with gray level T and for k , it is about a constant which should be determined by applying axiom (1), and for the gray level $T - 1$ which is belong to class 1 and recline 2 strides on the left of the hypothetical gray level T' should mark that all of the pixels which their gray are level $T - 1$ additionally with those that their gray level are T would be categorized into class 1. Of a whole a class, for ones with the gray level $T - 1$ to be member of class 1 and lie $i + 1$ strides on left of T' would specify that all of the pixels which their gray levels are $T - i, T - i + 1, \dots, T$ have been categorized into class 1.

We, then, have:

$$\begin{aligned} P_{1,T}(T-1) &= 0.5 + k(p(T-1) + p(T)) \\ P_{1,T}(T-1) &= 0.5 + k(p(T-i) + p(T-i+1) + \dots + p(T)) \end{aligned} \quad (4.3)$$

knowing that this is in agreement with axiom (3).

Then,

$$P_{1,T}(0) = 0.5 + k(p(0) + p(1) + \dots + p(T)) = 0.5 + k(p(class1)) \quad (4.4)$$

from axiom (1) it should be equal to 1 in that case the information gathered by categorizing and classifying the left-most gray level to class 1 is $-\log P_{1,T}(0) = 0$

$$1 = 0.5 + k(p(\text{class1}))$$

$$k = \frac{0.5}{p(\text{class1})} \quad (4.5)$$

Or we may rewrite the equation (1)

$$P_{1,T}(T-i) = P_{1,T}(T-i+1) + kp(T-1) \quad (4.6)$$

We then model the histogram as a “pseudo first order Markov source”. We use "Pseudo" because the value of k relies on the accumulative distribution of the gray levels in class 1. Same for class 2 we could have:

$$P_{2,T}(T+i) = 0.5 + \frac{0.5}{p(\text{class2})}(p(T+i) + p(T+i-1) + \dots + p(T+1)) \quad (4.7)$$

Also information emitted in allocating the class to a gray level g ; having the membership w.r.t. class 1 $= P_{1,T}(g_i)$ is then added by $-\log(P_{1,T}(g_i))$ [54]. The normalized class 1 dissemination is now $p(0)/p(\text{class1}), P(1)/p(\text{class1}), \dots, p(T)/p(\text{class1})$ (4.8)

The average information gathered by classifying and categorizing all its gray levels could be written now:

$$\text{Info}_1 = \frac{-p(0)}{p(\text{class1})} \log P_{1,T}(0) - \frac{p(1)}{p(\text{class1})} \log P_{1,T}(1) - \dots - \frac{p(T)}{p(\text{class1})} \log P_{1,T}(T) \quad (4.9)$$

Similarity for class 2

$$\text{Info}_2 = \frac{-p(N)}{p(\text{class2})} \log P_{2,T}(N) - \frac{p(1)}{p(\text{class1})} \log P_{2,T}(N-1) - \dots - \frac{p(T+1)}{p(\text{class2})} \log P_{1,T}(T) \quad (4.10)$$

Till now we get understanding the histogram with equal average variability as to which class 1 is and which class 2. Hence preferably it should choose that threshold for which $\text{info}_1 = \text{info}_2$ • the gray level is after then selected which minimizes $|\text{info}_1 - \text{info}_2|$ is minimized.

EXTENSION TO METHOD

A simple improvement is to think the second order statistic using the concurrence matrix is intricate. The (i,j) the element of this matrix and now form the chances of co-occurrence of gray levels i and j as adjacencies. Thereby, all elements in the matrix would be corresponding with 2 gray levels.

Figure 4.3: Co-occurrence matrix [54]

The T then presenting as a threshold will divides the matrix as in Figure 4.3. The T' , addressing a hypothetical gray level, is subsumed among the horizontal (vertical) rows typified by the gray levels T and $T + 1$. Each elements of the matrix above or below and to the left or right of ' are set to be member of class 1 or class 2. Now the membership of an element in the matrix in a class is based on the vertical distance from the threshold also the horizontal. Therefore, same as forgoing analysis, for the membership of an element $Q(x, y)$ in class1 we will have:

$$P_{1,T} = 0.5 + k \left(\sum_{i=x}^{i=T} \sum_{j=y}^{j=T} p(i, j) \right) \quad (4.11)$$

Now Axiom (1) can be adjusted by needing that the element of $O(0, 0)$ should have unity membership of assigning to class 1. $P_{1,T}(0)=1$.

$$k = \frac{0.5}{\sum_{i=0}^{i=T} \sum_{j=0}^{j=T} p(i, j)} \quad (4.12)$$

Same for an element $Q'(x', y')$, the membership w.r.t. class 2 is

$$P_{2,T}(Q') = 0.5 + \frac{0.5 \sum_{i=T+1}^{i=x'} \sum_{j=0}^{j=y'} p(i, j)}{\sum_{i=T+1}^{i=N} \sum_{j=0}^{j=N} p(i, j)} \quad (4.13)$$

The average information gathered by classifying the elements in class 1:

$$\text{Info}_1 = \frac{-p(0,0)}{p(\text{class1})} \log P_{1,T}(0,0) - \frac{p(1,0)}{p(\text{class2})} \log P_{1,T}(1,0) - \frac{p_{1,T}(T,T)}{p(\text{class1})} \log P_{1,T}(T,T) \quad (4.14)$$

Similarity, for class 2,

$$\text{Info}_2 = \frac{-1}{p(\text{class2})} \sum_{i=T+1}^{i+N} \sum_{j=T+1}^{j=N} p(i, j (\log P_{2,T}(i, j))) \quad (4.15)$$

APPLYING THE ALGORITHM ON THERMAL IMAGES

An example shows in Figure 4.4 below after applying image thresholding (explained in pervious section) on thermal images. The first image containg only one fever human while secound one contains one fever human and one normal human carring an object with high temrture.

Figure 4.4: two infrared images shown after and befor imgae thresholding.

4.1.2 Filling the Holes

After obtaining the binary image by temperature thresholding some small black spots remain in the face region, shown in Fig (a). These of black spots will affect the face detection step because we want the whole face region to be one single object, these black spots in the face regions are considered as holes. As we want to match a circle or an ellipse as a template to the face because of the similarity with the face shape (section 4.2), being of these additional spots (contours of small holes) might result in a wrong results in template matching. These holes in the face region will be filled by converting each 0 pixel value into 1. This step will be done by the MATLAB *imfill* command with the typical result shown in picture a and the face region after filling the holes (b) are shown in Figure 4.5.

Figure 4.5: A binary images bfore and after hole filling

4.2 Detection the objects of interest

Mostly the important part of this experiment is the detection of the object of interest which in our study, it is the face region and that would lead to detecting the human itself. So far we were able to find areas which their temperature are higher than human body temperature (which will be nominated as fever body) after applying the threshold filter on them and hole filling, we may now have several white regions in a black background that all of them may present as an object with high temperature. Among them we would still have some small spots left in background after running the algorithm or there could be some objects with small areas like cups of coffee, so the first step might be filtering these irrelevant objects from the image.

4.2.1 Selection of the objects

As shown in fig, some small objects may result as errors in the automated image Thresholding process. Automatic template matching process would be facilitated if the number of objects is smaller (as they will also count as target objects). The algorithm will give pixel area and coordinate of all objects, such that in this step the small objects can be removed from their pixel area as it is obvious that the very small objects cannot be human faces [28].

The algorithm successfully detects three objects as shown in Figure 4.6 By erasing this small irrelevant objects detected by considering their pixel area value the result [70] will be an thresholded image consisting only objects with pixel area value like the face region and the next step will be the finding and detecting the face regions among the left objects and it would be done by applying the template matching algorithm.

Figure 4.6: algorithm successfully detects all objects in the image

These objects with their pixel area value and coordinates were identified:

Grain Areas: 223pxl, 80pxl, 3pxl.

Grain centroid: [201.8744 65.3857],[210.6625 96.1625],[220.6250 90.2500].

The object with 223pxl is detected as Face

4.2.2 Template matching

The case of several objects with the similar pixel area of face is shown in Figure 4.7. The algorithm detects two objects in this image with 223pxl and 246pxl area, and template matching would have to be used to identifying the face.

Figure 4.7: thermal image before and after image thresholding, hole filling and filtering out the small objects

4.2.2.1 Template matching algorithm

METHOD 1 OF TEMPLATE MATCHING

In order to detect the object of interest among other objects Figure 4.8, the template matching is obtained using toolbox of Matlab™

Figure 4.8: image with several objects and object of interest [71]

Our main goal is to make a proper template for the object of interest which is most similar to it in both size and shape, by having the main image (having all relevant and irrelevant objects in it) as our input for the algorithm. It is important to indicate that for this method the template which is going to find the best match among all objects, should be a binary image with the boundary marked 1(white) and for the all the rest of the pixels marked 0(black). To produce the template from the object (object of interest), the object boundary in a sample image of human body (the face region) with uniform background will be used. For this step, Matlab™ is used to execute this process [71], an example has shown for symmetric objects shown in Figure 4.9.

Figure 4.9: template made from the object of interest [71]

To finding an object that best fit the template (Itm) in main image (Is). The orientation of the template and the object of interest in the main image of all objects, should not be the same as that as the template is like. The template (Itm) will search and get matched to the image (Is) in all of rotations and the best match will be detect as the detected object. The algorithm could use many of methods to discover the template in the image, including: Generalized Hough transforms, Normalize cross correlation to edge image and other forms of template match.

QUICK EXPLANATION ABOUT FUNCTIONS OF ALGORITHM IN MATLAB

Search Mode: The functions which template Itm will be start searching in main image Is :

Search Mode= 'hough': using the “generalized hough” transform to search and scan for template Itm in main image Is .

Search Mode= 'template': by using “crosscorellation” to search and scan for template Itm in the edge image of Is .

Rotate binary edge image (I, Ang): By rotating the edge image (I) in (Ang) degrees and besides the rotated output image would be a binary edge image too. The connectivity/topology of every edges/curves in the input image (I) would be retained and for the thickness of line in the curves of the output image (mat) we shall have 1 pixel. Also center of this rotation function is put on the center of the image, and for the dimensions of the output image (mat), it will be unlike from the input image so it would be adjusted such that the rotated image is completely within the image frame.

Figure 4.10: exapmle of how template will rotate [71][70]

Edge Type: the only apropos case of Search *Mode*='template'. This parameter will determine the all classes of image to which the template will be get the best matched (edge, gradient, grayscale).

Edge Type= 'sobel': The template (Itm) will get the best matched (cross-correlated) to the 'sobel' gradient map of the main image (Is).

Edge Type = 'canny': The template (Itm) will get the best matched (cross-correlated) to the 'canny' binary edge map of the main image (Is). In any other else cases: The template (Itm) will get the matched (crosscorrelated) to the grayscale version of the main image (Is).

Itm dilation: it is merely the apropos case of *Search Mode*='template'. The total of dilation for of the template. How plentiful the template line would be thickened (in pixels) for every sides earlier than cross-corelated with the image. The thicker the template boundary will results the better possibility to overlap with the edge of the object in the image and more firm the identification process. Nevertheless thick template can also lower the identification accuracy. For this parameter the default value is 1/40 of the mean dimension size of the template *Itm* [71].

Figure 4.11: edge dillation

CorlType: So the only applicable instance of *Search Mode*='template'. The process of template matching will go to the edge of image likely and to give high score for any place of the image with high edge density which can give high false positive, to elude this we consider few possible template match options, example for a diamond shape shown in figure 4.12.

Figure 4.12: exapmle of a diomand shap template matching in negative and posetive correlation [70][71]

CorlType='out': Using negative template (negative correlation) encircling the template contour (in small radius around the template line) however merely on the outside of the template. Crosscorrelation of this shape area with edges in a for example the canny image would be resulted by reducing the match score of the template matching in this area.

CorlType ='full': will use the negative template (negative correlation) around the template contour line (with a small radius around the template line) for all the inside and outside of the template. For crosscorrelation of these location areas with edges in the canny image, results will be reducing the match score of the template in this location.

And at last *CorlType* ='none': will Use the template as exactly it is.

The created template will start searching [70] [71] and get matched to the main image in varied rotations neat to find the best match, shown in Figure 4.13.

Figure 4.14: Binary template and main image as input and output will be be best score matched

METHOD II OF TEMPLATE MATCHING

The template that will be used for matching the shapes will made by extracting in the previous steps is a circle. The rationale logic of this option is because with regards to geometry

we need to clear the face regions that are roughly oval from other objects which radiates heat that their shapes are approximately like a rectangular. As long as the template made by deforming an affine map, this deformed shape will be an ellipse which we are expected to be more alike to a typical human face contour than to an irrelevant objects which their shapes like rectangular radiator (or their shapes may be like an ellipse, and we would have the size filtering based on pixel area, explained in section before). A block diagram of the steps elaborating in template matching function is shown in Figure 4.15.

Figure 4.15 A flowchart of steps the of template matching process

By setting as X a set of points x_i ($1 \leq i \leq N$) now entitle for coordinates of the template that is also a group of samples from the contour explaining the template. As we do for X , we now consider Y as a set of points y_i reporting the contour extracted from the object of our interest. The integer N assign to the amount of points of the template and objects of interest.

Considering

$$y_i = Ax_i$$

$$A = RS = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \quad (4.16)$$

where we have $\theta \in [0, 2\pi)$ as the rotation angle and λ_1 and λ_2 are positive extending parameters. Consequently R and S will be, separately, a rotation matrix and a symmetric positive definite matrix for those integrated function maps the circle (the template made by undeforming) to an ellipse and will continue rotating it by respecting to the initial reference frame. For the (2×2) matrix A , is hence a non-singular since $\det A = \det R \det S = \lambda_1 \lambda_2 > 0$, and that suggests the fact that the we cannot map the initial template into a shape with null area, and also degraded situations are eluded owing to the properties of the mapping algorithm [72].

By considering

$$z = \begin{pmatrix} \theta \\ \lambda_1 \\ \lambda_2 \end{pmatrix} \quad (4.17)$$

as the set of parameters that alternate the linear transformation A , and having

$$E: z \in \mathbb{R}^3 \mapsto E(z) \in \mathbb{R}^+ \quad (4.18)$$

So the minimum square distance of the two point sets from each other will meaning the deformed template and the object of interest

$$E = \sum_{i=1}^N ||y_i - Ax_i||^2 \quad (4.19)$$

The factual of the matching is to discover the group of parameters z^* that will minimize $E(z)$, and that lead to the following optimization problem

$$z^* = \operatorname{argmin}_z E(z) \quad (4.20)$$

Which is also equal to the root searching problem below?

$$\nabla_z E(z^*) = 0 \quad (4.21)$$

Where we have

$$\nabla_z := \begin{pmatrix} \frac{\partial}{\partial \theta} \\ \frac{\partial}{\partial \lambda_1} \\ \frac{\partial}{\partial \lambda_2} \end{pmatrix} \quad (4.22)$$

Which is the gradient but in components form by respecting to the state vector z . By expanding the equation (4.19) we can have: the energy function can be rewritten as,

$$E = \sum_{i=1}^N \left(2y_i^T y_i + 2x_i^T A^T A x_i - (x_i^T A^T y_i + y_i^T A x_i) \right) \quad (4.23)$$

For the energy function where

$$A^T A = \begin{pmatrix} \lambda_1^2 & 0 \\ 0 & \lambda_2^2 \end{pmatrix} \quad (4.24)$$

To finding the solution of the minimization problem, the gradient descent method will used.

GRADIENT DESCENT METHOD

Explain the Gradient descent method (steepest descent) we should say that it is a root searching family of algorithms. It is built on the examination that if the real-valued function $E(z)$ is steady differentiable in a neighborhood of a point $\bar{z}$, then $-\nabla_z E(\bar{z})$ will be the direction of steepest variation of $E(\bar{z})$ [73]. By considering E as a scalar valued function we then have:

$$\begin{cases} \text{Non negativity: } E(z) \geq 0 \quad \forall z \\ \text{Lipschitz continuity of the gradient: } \exists \kappa > 0: \|\nabla_z E(z_1) - \nabla_z E(z_2)\| \leq \kappa \|z_1 - z_2\| \quad \forall z_1, z_2 \end{cases}$$

An important suggestion of the properties of the above information is the Descent Lemma that will be explained next. **Descent Lemma** [74] with the hypothesis above will hold:

$$E(z + \tilde{z}) \leq E(z) + \tilde{z}^T \nabla_z E(z) + \frac{\kappa}{2} \|\tilde{z}\|^2 \quad (4.25)$$

Considering the iterative algorithm (gradient descent)

$$z_{n+1} = z_n - \delta_n \nabla_z E(z_n) \quad (4.26)$$

Where we have $\delta_n > 0$ and the integer n will label the iteration. The convergence of the gradient descent iterator will be implied by the Descent Lemma:

Convergence of the gradient descent algorithms [74] [72] Let consuming the sequence $\{z_n\}_{n=1}^{\infty}$ which generated by the gradient descent iterator by the Equation (4.23). So we will have $0 < \delta_n < 2/\kappa$ and the following asymptotic convergence answers will hold:

$$\lim_{n \rightarrow \infty} \nabla_z E(z_n) = 0 \quad (4.27)$$

For the convergence of the gradient descent algorithms it will be followed by iteratively updating the groups of parameters that explained the linear transformation A among to the iterator (4.23) so we finally have the solution of the problem (4.21) that will be the minimum of the distance function E .

$$\frac{\partial E}{\partial z_i} = \sum_{i=1}^N \left(2x_i^T \frac{\partial A^T A}{\partial z_i} x_i - \left(x_i^T \frac{\partial A^T}{\partial z_i} y_i + y_i^T \frac{\partial A}{\partial z_i} x_i \right) \right) \quad (4.28)$$

Where the first term in the right-hand side is zero for $z_i = \theta$.

The convergence of gradient descent algorithms also will measure the bounds for the updating step δ_n according to the Lipschitz constant κ . [70] which in this experiment we can use the step size 0.001. Iterations will be out until the difference between two following values of the energy function will get to less than a preset tolerance (10^{-6} used here), and for the converged value of E , the minimized least square distance between the deformed template and the object will considered, and the equate group of parameters z^* is the minimizer.

4.3 Detected objects tracking

Till now we have detected and clear our object of interest which is the face the human with fever, the last step is tracking the object. For this step worm-tracker programming will use.

4.3.1.1 WormTracker ImageJ

TRACKING AND ANALYSIS ALGORITHM

To explain how this algorithm works, we need to emphasize on some important. First of all, a moving object (here is a face region) should be maintained in the field of camera imaging at a ample magnification. Second, the object outline and head direction should be determined. Third, a spline entitle the midline of the object at every frame should be deduced, and at last, parameters associated to object locomotion and its shape should be quantified.

Image processing step [56]. That we already have it in pervious sections by Thresholding and now for this step for making it easier for tracking algorithm, captured images are processed through some steps to make a spline, and for the pixels in the original video frames are in greyscale having brightness values between 0 (black) and 255 (white), which the object will come in solid black color (Figure 4.16).

Figure 4.16: transforming all 1 value pixels to 0 and all 0 to 1.

Spline generation and centroid determination. The spline will make along the midline of the object shape by performing a cubic interpolation of midpoints (which in our case we have a solid shape so we don't have any bending activity). After that, it will divided into N segments by putting $N+1$ symbols at equal intervals, resulting in $N-1$ consecutive angles Figure 4.17, which can be numbered individually to measure bending belongings. For centroid, it will be set as the averaged position of the $N+1$ symbols [56].

Figure 4.17: Marking the object for tracking process

Movement path. Track-An Object could be restored by the travel path of that object alongside to the positions of either the centroid or any of the $N+1$ symbols according to the spline by integrating the stage movement information besides following objects images figure 4.16.

Speed, distance, and direction. These metrics are normally relied on the positions of the centroid over continues images while any of the $N+1$ symbols among the spline will be used, but centroid can be average of them. The Distance and Speed functions evaluated the mean speed

(mm/sec), the entire distance passed (both forward and backward) additionally the net distance passed by the object (straight-line distance between the first and last positions of the object) in the recording time. The entire distance passed can be measured relying on to the positions of either the centroid or any of the $N+1$ symbols among the spline because the net distance passed may be measured only by considering the centroid positions. Directionality will be measured by comparing a velocity vector made by linking the last and current centroids in two continues frames and a head vector shaped by clinking the current centroid and nose [57], so in the case of the estimation of the head vector onto the velocity vector is positive, the object is considered to be moving forward.

CHAPTER 5

This chapter is about simulation and experimental results that present the adequacy of the algorithm for some subject's identification. Simulated thermal images were made to test the vigor of the process with applying to some important scenarios, most important those involving the presence of different objects which radiating heat other than face in the field of view of the camera.

5. Illustration of the algorithm using simulated images

5.1 Objects used in simulation for template matching

The first step for simulating the thermal images, object with different shapes, characterizing typical face features and non-face features which are obtained from online source of infrared images [74,75]. And in the very first step, Infrared images will convert into binary images with pixel values 1 (white) and 0 (black) to make future steps more easily. The method of converting RGB images into binary images is explained in section (4.1.1) of chapter (4). Some of the binary shapes used in the simulations are shown in Figure 5.1.

Figure 5.1: simulated images for testing the algorithm [74,75]

5.1.1 Background of images:

The face and non-face objects which are shown in Figure 5.1 will be used for obtaining composite images having minimum a heat radiation source, two objects with face shapes in an image so as to simulate scenarios with multiple subjects all in a single thermal image. This will be applied by positioning the shapes obtained previously on a black background with dimension (350×450) . Many images were built with face and non-face shapes to test the efficiency of the algorithm, some of them shown in Figure 5.2.

Figure 5.2: Simulated binary images with face and non-face shapes [72]

5.2 Applying the algorithm on simulated images

The different images processed in the previous steps are used to apply and test the algorithm explained in chapter (4). The process of algorithm is shown in Figure 5.3.

Figure 5.3: Process of testing proposed algorithm using simulated images

As shown in Figure 5.3 the process of this step of algorithm involves different steps to implement the presence of face regions among objects. The process includes temperature thresholding, boundary extraction, template matching and Neyman-Pearson testing [72,73]. The algorithm will apply on all the simulated images. It will stop running and show the detected objects (if any) and then turn to the next image, until it finishes processing all the images. Processing and actions of the algorithm with details in some images are explained and shown in next section.

5.2.1 Step to step of template matching algorithm

In this section we presented how the input images will process in stages of the algorithm. An image which used to test the simulation of the algorithm is shown in Figure 5.2. As we see in

Figure 5.4. we only used face region without body, because body usually covered with clothes and the radiation of the body is much less than the face region and it would help us a lot when considering only face region by knowing the fact that if a person has fever, definitely the radiation of his face will be much more than his body which is covered with clothes. We can filter the body region in thresholding step and after that filter we will have only the face region, which is shown in Figure 5.4 where we can see that the body region has much lesser radiation and it filtered off from the images after Thresholding step.

Figure 5.4: Binary image with four objects (a-d) [74,75].

5.2.2 Boundary area extraction

Boundary lines extracted of the shapes of the objects (a-d) in Figure 5.5 are built in this step. The application and algorithm of boundary extraction is explained and shown in detail in section 4. Boundary lines obtained in this step are shown in Figure 5.5.

Figure 5.5: Contours of the objects (a-d) in Figure 5.4

5.2.3 Template matching

In this step of algorithm which is about template matching, a template (circular or elliptical) is twisted to get matched (in form of minimizing and rotating a suitable enough to match) the boundary shapes of the objects obtained in pervious step. The template matching algorithm and steps are explained in chapter 4. Best matches of templates (a-d) in Figure 5.5 and coverage area value of the least square distances are shown in table 5.1 . Conceded values gathered are now processed using the log likelihood ratio such in the equation (4.28), the equation which is intended to clear between face and non-face region within the Neyman-Pearson decision making criterion. Rewriting the equation (4.28):

$$\Lambda(E) = -\left(\frac{E-\mu_1}{\sigma_1}\right)^2 + \left(\frac{E-\mu_0}{\sigma_0}\right)^2 \geq \gamma \quad (5.1)$$

where the parameters of μ_1, μ_0, σ_1 and σ_0 are explained in chapter 4 and the value of threshold is $\gamma = 0.0011$. For the converged least square value we have the distances E equated to the contours in Figure 5.4 which are given in table 5.1.

Converged template
Converged value	3.10×10^{-4}	3.98×10^{-4}	4.02×10^{-4}	4.17×10^{-5}
$\Lambda(E)$	0.8551	-1.5957	-1.7282	-3.1166

Table 5.1: Showing the template (red boundary) converged with the contours of objects (a-d), their corresponding converged and ΛE values are also shown [70] [72].

As it is shown in table 5.1, $\Lambda(E)$ volume equated to the contour of the face region is above the threshold value (0.0011) and the log-likelihood ratio value is $\Lambda(E)$ of the non face contours (b-d) are below the threshold. The result will show that the face region with fever is excellency identified from the main image and the result showed in Figure 5.6.

Figure 5.6: Detected face region

As it is shown the pixel area values for the face region which have normal temperature or below, are filtered out in pervious steps, it will leave the image with only the region which is for the fever region in the step after, which is done by geometric recognition. In the next section experimental results of this thesis will be illustrated.

5.3 Illustration of experimental result of applying algorithm continues thermal images

Step by step by algorithm

5.3.1 Continuous thermal images of a objects

The thermal camera that has adjusted to set the normal human body temperature as reference temperature is connected to program start taking thermal images of objects walking through the path. Shown in Figure 5.7 are first thermal images.

Figure 5.7: continues thermal images from objects

5.3.2 Thermal image Thresholding will apply

Images will change to black and white

By applying the first step of image Thresholding, result will be the first black and white version of thermal images which will be processed by thresholding algorithm in nest step. Shown in Figure 5.8 all the images turn to black and white but the same order of the capturing.

Figure 5.8: applying first step of image thresholding

In this step the last part of image Thresholding will applied which turn all the images to last binary version (explained in chapter 4), as it is shown in Figure 5.9, there are only region

with higher temperature of normal human body left and also some small holes and irrelevant regions which will be solved in next section.

Figure 5.9: Results of infrared images after image Thresholding process

FILTERING THE HOLES AND IRRELEVANT SMALL REGIONS

After applying the image thermal thresholding there will be remained only the spots with higher temperature rather than a normal human body. As it is seen the fig there some spots left, some has high temperature and some are only holes. For this step if these spot are very small they will be considered as hole and will fill by hole filling algorithm explained in chapter 4, if they are bigger than holes, algorithm will find pixel area of all them including their coordinates. If the pixel area is much smaller than face pixel area defied in algorithm they will automatically erased, shown in Figure 5.10.

Figure 5.10: detecting all objects in image

Algorithm finds:

These objects with their pixel area value and coordinates were identified:

Grain Areas: 223pxl, 80pxl, 3pxl.

Grain centroid: [201.8744 65.3857],[210.6625 96.1625],[220.6250 90.2500].

The object with 223pxl is detected as Face

Object with 3pxl area will considered as a hole and will be filled and abject 80pxl area as irrelevant object and will automatically erased. Shown in Figure 5.11 is the result of this application.

Figure 5.11: detected face region

As it is shown in Figure 5.11 only face region remained in image.

5.3.3 Template matching

In case of having more than one object with higher temperature of the normal human body and if they have the pixel area similar to face, for detecting the face among them, template matching will apply. As it is shown in Figure 5.12 a human is holding a suitcase which is radiating heat like a fever human face and the pixel area is similar to face.

Figure 5.12: an infrared image having two human and an object

First algorithm will apply on the image and after thermal image thresholding and passing the filters to erase and fill the irreverent objects and filling the holes, two objects will remain in the image, shown in Figure 5.13.

Figure 5.13: detected high temperature objects

Till now, we have successfully obtained the only regions with higher temperature from the main image, also small objects and the holes are filtered out in a black background. In this step of having to objects similar to face template matching will be applied. Considering the pixel area values and the shape of the face in that particular point of view of camera, number of circular and elliptical templates would be considered with different pixel area values considering the estimated pixel area value for face region.

Matched template
Pixel area value	246	223
shape	Elliptical	circular

Table 5.2: Elliptical and circular template

Table 5.2 shows the results for best matches. The input would be the circular, elliptical and rectangular shapes with approximated pixel value of face region. In table is shown algorithm result for a circular and elliptical template on the objects (See Table 5.2). The elliptical matched has close pixel area values but it matched in horizontal direction, and is obvious that it cannot be a face region, but in the other hand, the object with circular match would be detected as a face region.

5.3.4 Tracking the path of detected object

5.3.4.1 *Making a video of continues images*

By putting alongside all the continues images of only the detected face and making a video of them, algorithm Processes entire movie even if first frame to contain no objects. (Subsequent frames might contain objects), it will identify the objects in each frame, and then determine which objects in successive frames are closest together. If these are within a defined

instance (the maximum velocity of the objects) and have similar area (maxAreaChange) they are assembled into tracks. Output of the algorithm will be the path that the objects of interest move including speed and the spot where it change direction.

In case of having multiple detected faces are within the distance determined by the maximum velocity, the nearest detected face is selected and the object is flagged in the output.

5.3.4.2 *Tracking the path*

In this step we track the movement of the only object in video which is the detected face. Minimum and maximum pixel area for the object is defined for algorithm so it will only track the detected face. Maximum and minimum velocity of the objects will be defined too so if there is a mistake in order of the images or a gap, it will be automatically corrected. In Table 5.3 features which should defined is shown:

minSize - Minimum Object Area (pixels^2):	<input type="text" value="100"/>
maxSize - Maximum Object Area (pixels^2):	<input type="text" value="400"/>
maxVelocity - Maximum Velocity (pixels/frame):	<input type="text" value="10"/>
maxAreaChange - Maximum area change (%):	<input type="text" value="30"/>
minTrackLength - Minimum track length (frames):	<input type="text" value="50"/>
bendThreshold - Threshold for turn :	<input type="text" value="2.0"/>
binSize - Size of bin for speed histogram (pixels/frame) (0=disable):	<input type="text" value="0.0"/>
☐ saveResultsFile - Save Results File:	
☒ showPathLengths - Display Path Lengths:	
☒ showLabels - Show Labels:	
☒ showPositions - Show Positions:	
☐ showPaths - Show Paths:	
☒ showSummary - show a summary of tracking	
☐ [roundCoord - round off coordinates]	
☒ smoothing - point smoothing	
☐ plotBendTrack - Quality control plots for thrashing analysis	
rawData - (0=off,1=XYcord,2=Ellipse,3=AreaPerimDist,4=Ellipse+Circ,5=BendCalc):	<input type="text" value="0"/>
bendDetect - (0=Off,1=Angle,2=AspectRatio,3=AR+Histogram):	<input type="text" value="2"/>
FPS - frames/s (0=try to load from file):	<input type="text" value="0"/>
backSub - On-the-fly background subtraction (0=off,1=F1RB15):	<input type="text" value="0"/>
threshMode - Thresholding method (only if backSub>0)	<input type="text" value="Otsu"/>
fontSize - Size of labeling font:	<input type="text" value="16"/>
<input type="button" value="OK"/> <input type="button" value="Cancel"/>	

Table 5.3: Adjustment of wrmtrack™ for the video [55]

ANALYZING AND BATCH ANALYZING

The algorithm of Worm-Tracking analyses has two graphic interfaces: Analyze and Batch Analyze. For both the methods, the spline data and equating stage data would be used as the input so it will generate quantitative data. Equating stage data will appointed automatically in the time that exact spline data are chosen [56]. Then the quantitative parameters will be categorized in two groups: Movement Analysis and the Bend Analysis. The Bend Analysis comprised plotting the bend trace and bend frequency spectrum, numbering the enormity and frequency of the maximum bends, enormity the sum of every bends averaged in the time, and

capturing the bending activities like RMS and maximum bend for every chosen bend (1 to $N+1$) [59]. The algorithms of Movement Analysis involved recreating the object travel path, capturing the object amplitude, scheming the speed and space of movements, and calculating the distance and duration of forward and backward movements. Every of these parameters but not the object amplitude and directionality can be calculated by considering the positions of either the centroid or any of the N symbols. The path of the selected object will be drawn, shown in Figure 5.14.

Figure 5.14: Object tracking

Several path drawn by application are shown in figure 5.15

Figure 5.15: example of other experimental objects

Chapter 6

6 Conclusions and Future work

6.1 Overall Conclusions

An algorithm, first to automatically identify the face regions with fever temperatures among all other faces and objects from infrared images has been proposed. Also this thesis proposes and verifies experimentally an approach for improving automatic fever detection in a dynamic human environment. This thesis represents a method which can automatically detect human faces with high temperature among other objects (having any temperature). Comparing to methods which are using now, this method is faster and more accurate and also doesn't need human labor. Methods which are currently used for fever detection needs a lot amount of time. In some cases they ask people to stand one by one in front of thermal camera to check their body temperature. In other cases there are small cabins which people will be asked to stay there for few minutes in order to check if they have fever or not. All these methods would take lots of time because it should apply on people one by one. Method presented in thesis is able to do automatic fever detection in a very short time. People will be asked to walk through a passage and infrared cameras. Thermal images would be taken from the walking people and after analysis, people who has fever will be detected. It will take very short amount of time. Also, presented algorithm is able to track objects of interests (human faces with fever) and draw their movement path. It will allow us to find location of the object of interest at any time. The proposed approach includes image Thresholding using Shanbhag method, template matching and moving objects tracking. The algorithm was illustrated through experimenting on several simulated images and also with images captured by an infrared camera. Experimental results confirm that the approach discriminate and track people with fever.

6.2 Future work

One of the important steps in the proposed algorithm is the image Thresholding that we could successfully detect high temperature objects from infrared images which obtained even without using a heat radiation source, it will help the automatic detection so easier. However the tracking section is very important too. In this study we propose an algorithm which can track the path of object traveling in 2-Dimensional, Hence the possible future work would be to examine and improve the algorithm in 3-Dimensional and also by having a 3-D map of traveling path we would able to improve this work to automatic tracking the object with moving robots.

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