Face Detection in Thermal Imaging Using Head Curve Geometry

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Abstract—**This paper presents an effective method to detect face in thermal imaging. It utilises the head curve geometry to extract the face from the images. Thermal imaging system is chosen due to its inherent nature of being immune towards drastic ambient light changes. A detailed face detection algorithm is explained in the paper, together with the performance comparison. Several conditions have to be fulfilled prior to the face detection. There should be one person facing the camera and no other external heat-emitting objects are captured by the camera. Overall, the face detection method demonstrates a high accuracy, which is 90.68% for the near images, 92.12% for the far images and 91.4% as an overall.**

Face detection; thermal imaging; head curve geometry; image processing; computer vision

I. Introduction

From the perspective of computer vision, face detection describes the ability of a computer to determine the identities of different individuals using certain computer software. It is also a form of biometrics, which automatically recognises a person based on the distinguishing features [1]. Face detection offers a non-intrusive way of identifying a person as the camera can capture one's face from certain distances away. Hence, it is widely used in a vast repertoire of applications. One of them is access control, in which the user's face is verified through the face detection application in the webcam before a laptop can be used. Besides that, face recognition is very imperative in medical imaging field. A person's face is extracted using thermal imaging system to subsequently measure one's body temperature from the heat emitted at the inner canthus near the eye [2]. The most dominant application of face detection is in the surveillance system, commonly used by the authority to locate criminals and terrorists [3].

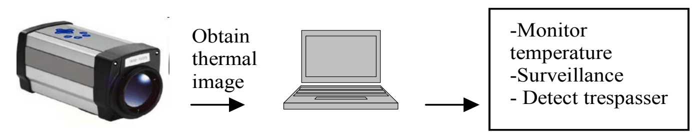
Previously, numerous face recognition researches were conducted in visual spectrum. The captured images are highly dependent on the lighting conditions from the external environment. This visual imaging system poses one major problem when the outdoor environment is dark. As a result, detecting faces using the conventional digital colour images is very difficult and can lead to performance degradation. In order to overcome this issue, thermal or infrared imaging system is introduced, as it functions optimally, regardless of the lighting conditions [4].

Apart from that, manpower is one of the factors, which should be taken into accounts in face detection. Due to human nature, exhaustion is inevitable; a person's attention can deteriorate after long working duration [5]. Therefore, an automated system is designed for detecting various faces continuously without decreasing the performance. In addition, various techniques deployed in the thermal imaging systems are emulated from those used in the visible spectrum. The most recent approaches are the Haar features and GentleBoost algorithm used by the authors to detect facial components from the thermal images [6]. Another method is Support Vector Machine (SVM) used in [7] to detect human faces in a thermal video. However, the author claims that the SVM method is time-consuming due to the extra time needed for sub-sampling and training. Thus, in this paper, a straight forward face detection algorithm is proposed using the head curve geometry. Since no redundant statistical training is required, the aforementioned algorithm is fast, simple and effective, thus making the automated thermal imaging system reliable

The paper is arranged as followed: Section II describes the system model, followed by the proposed algorithm in Section III. Experimental results and performance comparison are explained in Section IV. Lastly, Section V reports the conclusion and envies some future works.

II. Thermal Imaging Based Face Detection System

The proposed face detection system using thermal imaging system is shown in Fig. 1. This system comprises a thermal camera, coupled with a computer installed with the MATLAB programming (version R2009b or later) and an appliance for further image processing.



(a) Thermal Camera (b) Computer (c) Appliance

Figure 1. Thermal Imaging Based Face Detection System

A. Thermal Camera

A thermal camera is deployed in this paper. The model of the camera is Thermo Vision A-20M, produced by the FLIR system. It is not only capable of gauging temperature ranging from -20^{0}C to 900^{0}C, but also features a perfect resolution of 320x240 pixels. The refresh rate is 50/60 Hz. Several choices of connectivity are available and one of them is the IEEE-1394 Digital output, which promotes a fast image and data transfer. Meanwhile, to install multiple cameras in a network, Ethernet connectivity is an ideal option.

B. Computer and applicance

The computer/laptop receives the detected images from the thermal camera and processes them using the MATLAB program. Once the face is extracted from an image, the output is sent to an appliance, such as the temperature monitoring system, tracking trespasser in the dark, and surveillance system for further analysis.

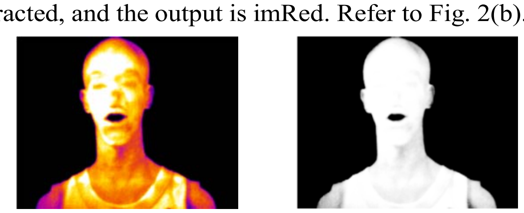
III. HEAD CURVE GEOMETRY BASED FACE DETECTION ALGORITHM

The face detection algorithm operates based on the head curve geometry, in which the face is extracted after five points are located on the head boundary, followed by drawing a curve around the neck region. This method is modified from Z.Y Chew's work in [8], H.L. Lim's work in [9] and J.H. Hui's work in [10]. There are three main components in the algorithm, namely pre-processing, points searching, and curve drawing.

A. Pre-processing

Step 1: Acquire the thermal image. Refer to Fig. 2(a).

Step 2: As the Fig. 2(a) is a RGB image, the red component is extracted, and the output is imRed. Refer to Fig. 2(b).



(a) (b)

Figure 2. (a) RGB Thermal Image (b) Red component from RGB, imRed image

Step 3: Convert imRed into black and white image, bwRed. Refer to Fig. 3(a).

$$\text{bwRed(m,n)} = \begin{cases} 1, imRed(m,n) > thIm \\ 0, otherwise \end{cases} \quad (1)$$

Where m,n are the row and column matrix coordinate and *thIm* is the threshold value.

Step 4: Generate a disk element, seM with a radius, *rDisk*.

Step 5: Perform morphological closing on bwRed. The output is bwClo.

Step 6: Generate bwFil image by filling the holes in bwClo. Refer to Fig. 3(c).

(a) (b) (c)

Figure 3. (a) bwRed (b) bwClo (c) bwFil

Step 7: Obtain the object's boundary and save it as coordinate arrays.

B. Points searching

Step 1: From the object boundary, find the mean x coordinate. The highest point (minimum y coordinate) between the intersection points of the boundary with the vertical x mean line is the starting point. From the starting point, check *dVar* pixels in clockwise and counter clockwise direction to search for two peaks - P_c and P_{cw}. The highest point between 2 peaks is the head top point (HeadPpoint). Refer to Fig. 4(a).

Step 2: Find LeftMean and RightMean points by intersecting the boundary with the horizontal y mean line. Refer to Fig. 4(f), (g).

Step 3: Traverse from the HeadPpoint to the LeftMean in counter clock wise direction to locate the most outer point (the most left) by comparing the x (horizontal) coordinates. The pixel with the minimum x value corresponds to the Most Left Point. Refer to Fig. 4(b).

Step 4: Repeat the similar operation in step 3. Traverse from the HeadPpoint to the RightMean in clock wise direction to seek for the most outer point (the most right). The x (horizontal) coordinate of each pixel are compared and the pixel, which has the maximum x value is chosen as the Most Right Point. Refer to Fig. 4(c).

Step 5: Find the index difference, *iDistance* between the Most Left Point and the HeadPpoint. Check for *iDistance* pixel from the Most Left Point in counter clock wise direction to locate the most inner point (the most right), through the comparison of the x coordinates. The pixel with the maximum x value is the Left Neck Point. Refer to Fig. 4(h), (d).

Step 6: Perform the same procedure in Step 5, by replacing the Most Left Point with the Most Right Point. The search direction is clock wise direction to find for the most inner point (the most left). The pixel with the minimum x value is the Right Neck Point. Refer to Fig. 4(e).

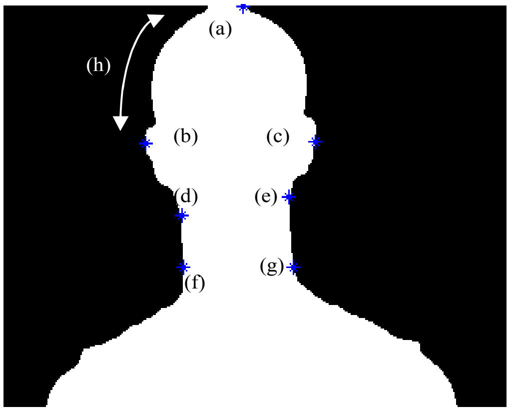


Figure 4. (a) HeadPpoint (b) Left Most Point (c) Right Most Point (d) Left Neck Point (e) Right Neck Point (f) LeftMean (g) RightMean (h) *iDistance*

C. Curve Drawing

Step 1: Determine the center point, cenDraw for the curve, using the x and y coordinates from the Left Most Point and the Right Most Point. The average of the y coordinates (cenDrawY) from both points yields the y coordinate of the cenDraw.

Step 2: Locate two points (point A and point B) by extending the horizontal y axis at the value of cenDrawY across the head boundary. Use the average of those two points to calculate the x coordinate for cenDraw.

Step 3: Measure the distance from the point A to cenDraw and from the point B to cenDraw. The maximum value between two measured distances is the radius for the curve.

Step 4: Use the cenDraw and the radius to plot the curve on the head boundary. Refer to the Fig. 5(a).

Step 5: There should be two separate objects after the curve is drawn. The object, which has the HeadPpoint in the boundary shall be selected to extract the head shape out. Refer to Fig. 5(b)

IV. Experimental Results

Few experiments are performed to find the optimal values for certain parameters mentioned in the algorithm. The setting of the experiment is in the office building of the Faculty of Engineering and Technology (FET), Multimedia University (MMU) Melaka. The diagram below (Fig. 6) portrays the set up of the thermal camera.

(a) (b)

Figure 5. (a) bwFil image with cenDraw point and a curve (b) The extracted head shape in RGB image

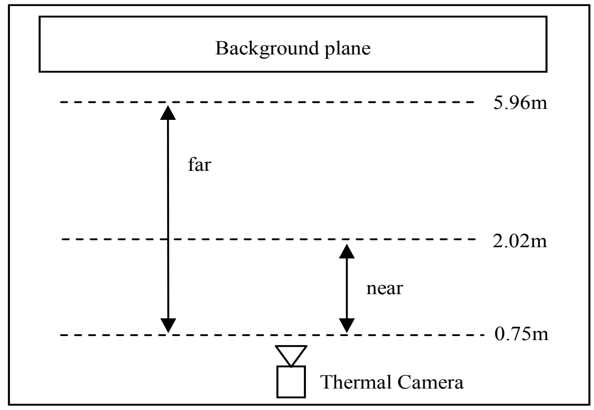


Figure 6. Location of the thermal camera in the experimental setups. The distance readings are measured from the thermal camera.

First and foremost, three sets of 10000 thermal images (Set 1,2,3) with 1 test subject standing in between the background plane and the camera are prepared. Set 1 thermal images are evaluated with the algorithms to optimise the *rDisk* and *dVar* parameters. Meanwhile, thermal images from Set 2 are taken with the subjects standing in the near region, as shown in Fig. 6, and the final set of thermal images are captured for those subjects in the far region.

The tool to measure the algorithm performance is the Operator Perceived Activity (OPA) [11]. A human operator is needed to analyse the algorithm and a result is produced. Subsequently, the thermal images are tested with the algorithm. The testing results are compared with those of the human operator. The interpretation percentage (whether the faces are successfully extracted) that is accepted by both human operator and the algorithm defines the accuracy of the face detection system.

rDisk is the radius size used to plot a disk-shaped structuring element for the morphological process in Step 4 at Section III A, meanwhile *dVar* describes number of pixels to be searched to locate P_c and P_{cw} in Step 1 at Section III B. Several different combinations of rDisk and dVar values are tested to find the optimised parameters. From the table below, the optimised values for dVar and rDisk are 4 for both.

TABLE I. Overall Accuracy For Different Values of rDisk and dVar

rDisk	**dVar**				
2	2	3	4	5	6
3	90.34%	91.67%	89.17%	88.79%	86.26%
4	90.58%	92.47%	94.56%	91.35%	90.04%
5	87.11%	88.44%	88.93%	90.38%	92.90%
6	87.01%	90.31%	91.59%	93.66%	94.12%

Set 2 and 3 are utilised for performance comparison. In this paper, the proposed method is compared with distance from centroid method in [12] and ellipse method in [13]. The obtained accuracy is shown in Table II as below.

TABLE II. OVERALL ACCURACIES OF DIFFERENT ALGORITHMS FOR NEAR AND FAR DISTANCES

Data Set	Algorithms		
	Proposed method	**Distance from centroid**	**Ellipse**
Near Set 2	90.68%	31.68%	69.81%
Far Set 3	92.12%	21.53%	43.92%
Overall accuracy	91.4%	26.61%	56.87%

From the table above, the proposed algorithm can achieve approximately 90% accuracy for samples of images taken at the near and the far regions. The result is superior to those of the other two methods.

(a) (b)

Figure 7. (a) Image at the near region (b) Image at the far region

V. CONCLUSIONS

In this paper, a non-training face detection algorithm has been proposed using the head curve geometry. It encompasses pre-processing, points searching and curve drawing. The overall algorithm works well with the thermal imaging system, in which the thermal camera captures the images and sends them to a computer for image processing. Thermal imaging based face detection has various types of applications, which include temperature monitoring at the airport and surveillance system in the dark. Apart from that, the system is capable of achieving as high as 91.4% in the overall accuracy. In future, an omnidirectional (360^0) view is integrated with the thermal imaging system to recognise multiple faces, using minimum hardware and cost effective setup.

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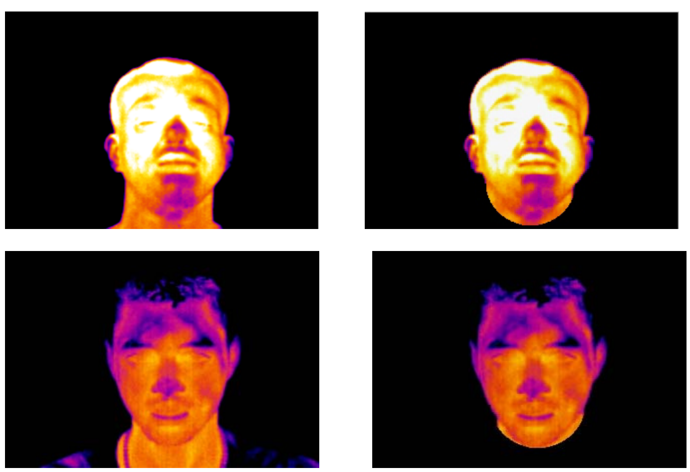

Figure 8. Thermal Images (Left) and the extracted faces using the proposed algorithm (Right)