

Thermal Imaging for Anxiety Detection

Ioannis Pavlidis
Honeywell Inc.
Minneapolis, MN
ioannis.pavlidis@honeywell.com

James Levine
Mayo Clinic
Rochester, MN
levine.james@mayo.edu

Paulette Baukol
Mayo Clinic
Rochester, MN
baukol.paulette@mayo.edu

Abstract

We propose a revolutionary concept for detecting suspects engaged in illegal and potentially harmful activities in or around critical military or civilian installations. We investigate the use of thermal image analysis to detect at a distance facial patterns of anxiety, alertness, and/or fearfulness. This is a totally novel approach to the problem of biometric identification. Instead of focusing on the question “who are you” we focus instead on the question “what are you about to do”. Documented preliminary results clearly indicate the feasibility of the idea.

1 Introduction

Alertness, anxiety, and even fear appear to accompany people that are involved in terrorist or illegal activities at the time of their action. In the interest of brevity we will usually identify this set of feelings with the word anxiety only. Since those symptoms are produced by the sympathetic system [1] cannot be totally controlled. Therefore, they potentially constitute a very powerful biometric that is extremely difficult to conceal. This biometric can provide valuable clues to security personnel of critical facilities about potential suspects “immune” to identification biometrics (e.g. first time offenders).

When a subject experiences elevated feelings of alertness, anxiety, or fear increased levels of adrenaline regulate blood flow. Redistribution of blood flow in superficial blood vessels causes abrupt changes in local skin temperature. This is readily apparent in the human face where the layer of flesh is very thin. The human face and body emit both in the mid- (3-5 μm) and far-infrared (8-12 μm) bands. Therefore, mid- and far-infrared thermal cameras can sense temperature variations in the face at a distance, producing 2D images (thermograms).

In the rest of the paper we provide in Section 2 an overview of our methodology. In Section 3 we describe in some detail our experimental design, the experimental protocol, and the experimental results.

Finally, we conclude the paper in Section 4 by mentioning briefly our research plans for the future.

2 Overview of our methodology

The objectives of our effort could be summarized as follows:

- (a) Investigate the thermogenic potential of the human face. In other words, establish if mild psychosomatic activities have a thermal effect on the subject’s face significant enough to be detected in thermal imaging.
- (b) Provided that the facial thermogenic capacity appears significant, investigate the uniqueness of the facial thermal patterns corresponding to various activities. If there is a one to one correspondence between facial thermal patterns and psychosomatic activities, then it will be feasible to detect unambiguously particular activities of interest. This detection could be done either through observation or a machine vision algorithm.
- (c) Work out plausible physiological and evolutionary explanations for the observed patterns. This would strengthen the validity and confidence of our preliminary conclusions, particularly because we could not afford a statistically significant test sample.

We used an uncooled thermal camera in the far-infrared (8-14 μm) by Raytheon (the ExplorIR model – see Figure 1). As we said earlier, the human body and face emit in both the mid- and far-infrared bands. Therefore, ideally, we should also have had a mid-infrared camera (3-5 μm) to compare the information content in both bands. The nominal temperature sensitivity of the ExplorIR is $\text{NEDT} = 0.15^{\circ}\text{C}$ but this performance is almost never attained (NEDT stands for Noise Equivalent Temperature Difference).

We estimate that the actual temperature sensitivity of ExplorIR is usually above 0.5°C . This is only a fair

amount of facial temperature resolution and probably masked out a certain amount of information in our experiments. Nevertheless, the deficiencies of our experimental set-up could be seen in a positive sense: if given our crude equipment we could successfully address our objectives (see previous paragraph), then the amount of thermal information emanated from the face should be substantial. In other words, the feasibility argument of our idea could only be strengthened.



Figure 1. The ExplorIR far-infrared camera by Raytheon.

3 Experimentation

3.1 Experimental design

Given the limited resources at our disposal we designed the following experimental methodology to achieve our objectives:

- (a) We assembled a small group of subjects (6) to use in our experiments.
- (b) We administered a battery of tests to each subject in turn. The tests were taking place in a room with average temperature about 70^o F. The subject under testing was imaged frontally with the ExplorIR thermal camera. The frames were recorded continuously in a standard VCR for later access and analysis.
- (c) We studied the test results (videotapes) using image analysis methods that will be described later in the Section.
- (d) Where appropriate, we re-ran the experiments and performed measurements not with the thermal camera but with a conventional transducer of an invasive nature. We compared the results between the imaging and the non-imaging methods to check for inconsistencies.

3.2 Experimental protocol

Specifically, we administered the following tests on each subject:

- (a) **Subject sits quietly in the dark (10 min).** The purpose of this exercise was to relax the subject and amplify the effect of the upcoming sudden event. Relaxation was meant to isolate the effects of other stress factors that the subject may have carried over from earlier events during his/her day and help us establish a baseline in the thermal imagery.
- (b) **Subject receives a startle stimulus (instantaneous).** A loud noise (60 dB) was produced very close to the subject without his/her knowledge. The purpose of this exercise was to temporarily increase the levels of alertness, anxiety, and fear on the subject.
- (c) **Subject sits quietly in a dimly lit room (10 min).** The intention here was to allow the subject to revert to his/her baseline status and verify the corresponding symmetry in the thermal imagery.
- (d) **Subject chews gum (10 min).** The purpose of this exercise was to produce facial thermal patterns related to other non-anxious activities and check if there were any overlapping in the feature space. The subjects were provided with 8.4 g of calorie free gum and instructed to chew at precisely 100 Hz (approximates chewing frequency at our institution) using a metronome. Enforcing a specific chewing frequency was a prerequisite for a fair comparison of results among subjects.
- (e) **Subject sits quietly in a dimly lit room (10 min).** This break was again meant to isolate the effects of the past activity (chewing gum) before the next activity starts.
- (f) **Subject walks at 1 mph on a treadmill (10 min).** Finally, we were interested to measure the facial thermal effect of the most common aerobic activity – leisure walking. This is by default the activity that all human subjects are engaged around critical or non-critical installations just by the virtue of approaching in or receding out of there. It was of obvious value to check if this thermal signature could clutter the thermal signature produced by an anxiety event.

We recorded the thermal imagery on videotapes. Upon the completion of the experiments we digitized the content of the videotapes and segmented snapshots out of the video stream. The snapshots were representative of all the critical phases per activity and per subject. Typically, we segmented out snapshots from the beginning, middle, and final stages of an activity. In the selected snapshots, we segmented the face of the subject from the rest of the background using

an image processing toolbox. Then, we segmented the face itself into 5 areas (see Figure 2):

1. Periorbital area.
2. Nasal area.
3. Cheeks (left and right).
4. Chin area.
5. Neck area.



Figure 2. Visualization of the 5 facial areas under monitoring in our experiments.

We performed image measurements on the entire face area as well as the above 5 designated sub-areas. The pixel values in the imagery did not represent actual temperatures but corresponding false colored digital values. The ExplorIR camera uses a false colored index where hues of white represent the highest temperatures and hues of blue the lowest temperatures. Between white and blue, hues of red, yellow, and green represent intermediate temperatures in that order. We mapped the RGB triplet of each pixel value to a single value in the range $0 \div 255$ by applying the inverse linear rainbow transformation. In this new scalar pixel representation 0 stands for the lowest temperature and 255 for the highest temperature. Using this last representation we performed pixel value averaging on the entire face as well as its 5 designated sub-parts for every snapshot in our experimental stockpile.

3.3 Experimental results

For the 3 primary activities that we were monitoring: response to startle stimulus, gum chewing, and mild aerobic exercise we witnessed significant and measurable facial thermal changes at a distance. Regarding the particular thermal patterns associated with each activity we found the following intriguing results:

- (a) **Response to Startle Stimulus.** In all subjects, startle was accompanied by instantaneous

(less than 300 msec) increases in blood flow around the eyes that was independent of face or eye movement (see Figure 3). There were other concomitant facial changes namely, cooling over the cheeks and warming over the carotid (see Table 1). Interestingly, the mean temperature of the nasal area remained more or less the same (see Figure 3 (c)). All changes reverted to pre-startle, resting values within about 1 minute.

- (b) **Gum Chewing.** Gum chewing was accompanied by near-instantaneous, highly localized chin warming (see Figure 4). When chewing ceased, the thermal signature over the chin reverted to baseline (see Table 2). The physiological congruity of the regional, thermal changes was demonstrated by measuring oxygen consumption with the same chewing stimulus. The measurements were performed with an indirect flow-over calorimeter (SensorMedics 229; Yorba Linda, CA). Expired air from the subjects was collected using a specifically designed ($0.3 \times 0.2 \times 0.1$ m) facemask that allowed unopposed jaw movement. Oxygen consumption (VO_2) increased with chewing in all subjects and with rest reverted to baseline (see Table 3). The study concluded that chewing gum produces a characteristic and measurable thermal pattern in the far-infrared spectrum. In addition, we concluded that chewing gum is sufficiently exothermic that if a subject chewed gum during waking hours and changed no other components of energy balance, yearly weight loss of greater than 5 kg body fat (~ 10 kg body weight) might be anticipated. The results of the chewing gum portion of our effort were published in the *New England Journal of Medicine* [2] and raised national media interest [3].
- (c) **Leisure walking.** Leisure walking was accompanied by gradual cooling of the nasal area (see Figure 5). Every other facial area was maintaining pretty much the same temperature levels. From the physiological point of view this can be ascribed to a more active breathing pattern.

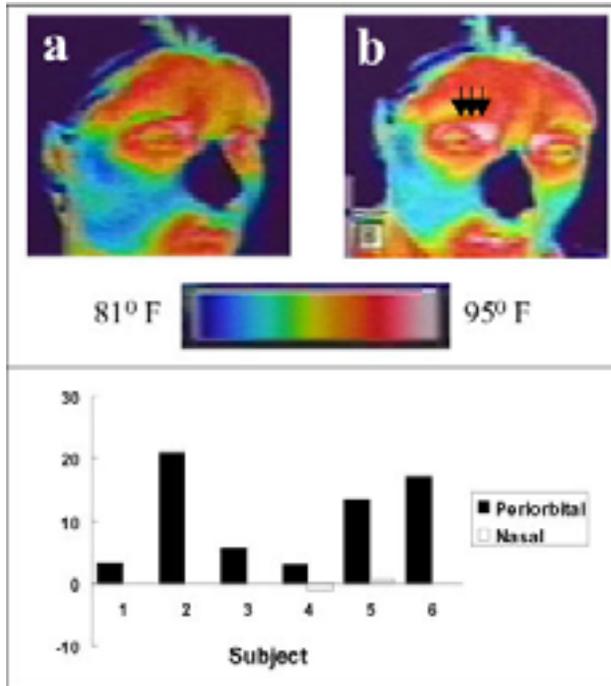


Figure 3. Thermal images of the face for a subject (a) before and (b) 300 msec after an instantaneous startle. Arrows indicate local warming in the periorbital area. The color bar depicts the false coloring scheme from the lowest (81° F) to the highest (95° F) temperature. (c) Changes of the average pixel value in the periorbital and nasal areas with auditory startle. The changes are depicted for each subject ($n=6$ subjects). Positive deviation represents local warming and negative deviation, cooling.

Table 1. Average thermal changes in various parts of the face before and after the startle stimulus (6 subjects). SD stands for Standard Deviation. The digital pixel values in the thermal imagery were normalized to the range 0-255 with 0 corresponding to 81° F and 255 to 95° F.

Average Pixel Values		
	Before Startle	Right After Startle
Periorbital Area	204 ± (SD) 59	214 ± (SD) 54
Cheeks	170 ± (SD) 77	148 ± (SD) 75
Neck Area	230 ± (SD) 20	242 ± (SD) 19

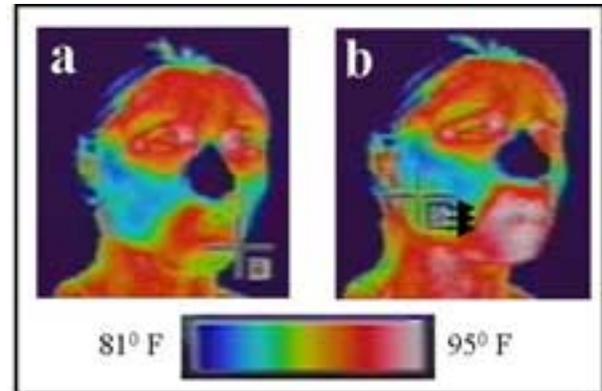


Figure 4. Thermal images of the face for a subject (a) before and (b) after chewing. Arrows indicate local warming in the chin area. The color bar depicts the false coloring scheme from the lowest (81° F) to the highest (95° F) temperature.

Table 2. Quantification of chin warming before, during, and after chewing on a population of 6 subjects. SD stands for Standard Deviation. The digital pixel values in the thermal imagery were in the range 0-255 with 0 corresponding to 81° F and 255 to 95° F.

Average Chin Pixel Value		
Before Chewing	During Chewing	After Chewing
195 ± (SD) 67	242 ± (SD) 16	197 ± (SD) 68

Table 3. Quantification of physiological congruity for chin warming associated to chewing (6 subjects). SD stands for Standard Deviation. The numbers denote liters/min of VO₂ consumed by the subjects before, during, and after chewing.

Average VO ₂ Value		
Before Chewing	During Chewing	After Chewing
0.18 ± (SD) 0.03	0.22 ± (SD) 0.04	0.18 ± (SD) 0.03

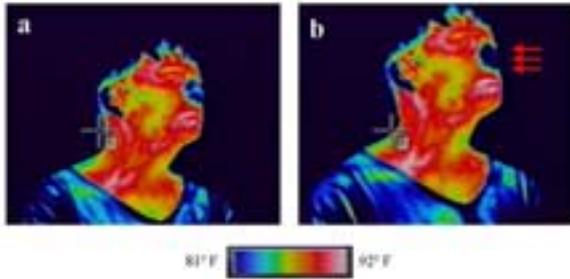


Figure 5. Thermal images of the face for a subject (a) before and (b) during leisure walking. Arrows indicate local cooling in the nasal area. The color bar depicts the false coloring scheme from the lowest (81° F) to the highest (92° F) temperature. We have compressed the temperature range from 81° - 95° F in the previous images down to 81° - 92° F in the present images to make more apparent the nasal cooling effect.

In conclusion, different activities appear to produce distinct non-overlapping facial thermal patterns. Therefore, the detection of these activities appears to be amenable to machine automation. The most interesting and complicated pattern is the one associated with anxiety. As we mentioned earlier, right after the startle stimulus we consistently recorded periorbital warming associated with increased blood flow around the eyes. This extra blood to the eye musculature was primarily redirected from the cheeks, as the concomitant cooling of the cheek area was indicating (see Table 1). Some of the extra blood may have been coming from the rest of the body as the warming of the carotid vein was indicating. The whole pattern makes physiological and evolutionary sense since it represents (a hitherto unidentified) mechanism to facilitate rapid eye movements during preparedness for flight. This physiological explanation strengthens the validity of our results, otherwise backed by only a small statistical support.

In conclusion, different activities appeared to produce distinct non-overlapping facial thermal patterns. Alertness, anxiety, and fear are most likely mediated by the sympathetic/adrenergic nervous system. To verify this hypothesis we administered subcutaneously minute doses of adrenaline in a subject's arm. The purpose was to check if changes in local thermogenesis associated to the adrenaline shot were consistent in time course and nature with the periorbital changes in blood flow we observed in the startle experiment (see Figure 3). Locally, adrenaline resulted in vasoconstriction, as it is evident by the blue cold spot indexed by arrow b2 in Figure 6 (b). As a result, blood redirected to the outer edges of the arm producing the white-hot area evident in the image. Compare this pattern with the cheek cooling and concomitant periorbital warming after the startle event in Figure 3. It is well known that any sympathetic function is impossible to be eliminated or controlled

through training or self-restrain. Consequently, countermeasuring an anxiety detection system will be a very difficult business.

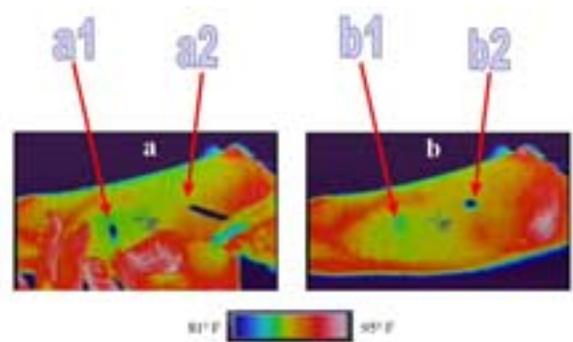


Figure 6. Thermal image of a subject's arm (a) at the time of injection and (b) a few seconds after. The arrow a1 points to the injection point of a neutral shot (1% lidocaine). The neutral shot was used for comparison purposes. The arrow a2 points to the injection point of an adrenaline shot (10 μ l of 10 mg/ml epinephrine with 1% lidocaine). The arrow b1 points to the same point as arrow a1 but a few seconds after the shots. The arrow b2 points to the same point as arrow a2 but also a few seconds after the shots.

4 Future work

Although, the results of our experiments so far are not only intriguing but also extremely promising, our research is far from being conclusive. One major issue we have to address before we proclaim feasibility for an anxiety detection system is the issue of baseline universality. We have demonstrated rather convincingly, that if we monitor an individual from before the time the anxiety sets in, then we can easily detect the transition from the calm state to the anxious state. The change in the facial thermal pattern at the time of the transition is drastic. In practical situations we cannot hope to have the thermal history of the subjects under surveillance. Suspects who appear around critical installations will already be anxious. In these cases we can only hope to detect anxiety if we establish that there are baseline thermal features invariant across the human race. Congruently, we need to establish that there are anxiety thermal features that are universal. Only then, we will be able to discriminate anxious from non-anxious subjects at any point in time without any apriori knowledge of the individual thermal histories.

We are very optimistic that such invariances do exist and will pinpoint them in the course of our continued research. Our prediction is based on physiological and evolutionary arguments hinted by our early experimentation. Our main finding was that in anxious

states blood is locally redirected to the periorbital musculature to facilitate rapid eye movements. This creates a local energy imbalance that alters the relative average thermal ratios in the face. Although, in absolute terms the average thermal values of the face areas may differ from subject to subject, the relative ratios may be less variable and representative of a consistent energy management system. In this respect, ratios skewed too heavily in favor of the periorbital area would be a sure sign of anxiety. Thermal ratios represent one potential invariant scheme among many that we will investigate.

We intend to achieve our main goal (invariant features) and a number of other important objectives through continued technology development, data collection, experimentation, and comprehensive evaluation.

5 References

- [1] M. Fendt and M.S. Fanselow, *Neurosci Biobehav Rev*, Vol. 23, pp. 743-760, 1999.
- [2] J. Levine, P. Baukol, and I. Pavlidis, "The Energy Expended in Chewing Gum," *The New England Journal of Medicine*, Vol. 341, No. 27, 1999.
- [3] http://www.htc.honeywell.com/people/ioannis_pavlidis/Articles/articles.htm