A Research on Facial Visual-Infrared Stereo Vision Fusion Measurement for Internal State Estimation

(内部状態推定のための可視・赤外ステレオビジョン融合測定に関する研究)

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Abstract

Our main aim is to propose a vision-based measurement as an alternative to physiological measurement for recognizing mental stress. The development of this emotion recognition system involved three stages: experimental setup for vision and physiological sensing, facial feature extraction in visual-thermal domain, mental stress stimulus experiment and data analysis based on Support Vector Machine (SVM). In this thesis, 3 vision based measurement and 2 physiological measurement was implemented in the system. Vision based measurement in facial vision domain consists of 3 ROI`s temperature value and blood vessel volume at supraorbital area. Two physiological measurement were done to measure the ground value which is heart rate and salivary amylase level. We also propose a new calibration chessboard attach with fever plaster to locate calibration point in stereo view. A new method of integration of two different sensors for detecting facial feature in both thermal and visual is also presented by applying nostril mask, which allows one to find facial feature namely nose area in thermal and visual domain. Extraction of thermal-visual feature images was done by using SIFT feature detector and extractor to verify the method of using nostril mask. Based on the experiment conducted, 88.6% of correct matching was detected. In the eyes blinking experiment, almost 98% match was detected successfully for without glasses and 89% with glasses. Graph cut algorithm was applied to remove unwanted ROI. The recognition rate of 3 ROI`s was about 90-96%. We also presented new method of automatic detection of blood vessel volume at Supraorbital monitored by LWIR camera. The recognition rate of correctly detected pixel was about 93%. An experiment to measure mental stress by using the proposed system based on SVM classification had been proposed and conducted and showed promising results.

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Chapter 1

Introduction

1. The current focus of mental stress research

There are escalating changes in technology and society, which bring growing demands for better techniques in dealing with wellbeing by containing everyday unavoidable life pressures and challenges. Stress is the leading threat to people because these daily demands cannot be satisfactorily handled, and is a risk to the health and social aspects of life. The term, *stress*, introduced by *Selye*, defined stress as the –specific response of the body to any demand of change. In general, stress is a complex reaction pattern that often has psychological, cognitive and behavioral components[1]. It can essentially be used to describe the wear and tear of the body experiencing changing environments, thus giving three main facets-inputs stimulus, processing and evaluation, and response[2].

It has been widely accepted that stress, when sufficiently powerful so that it overcomes defense mechanisms, has a range of severe impacts on immune and cardiovascular systems on individuals. As stress become chronic, it makes individuals more vulnerable to infections and incurable diseases, and slows down the body`s recovery process [3]. In addition, stress causes financial burdens on society.

Various response measures have been used to interpret stress level and fluctuations. The response measures reflect reactions of the individuals and their body to stressful situations. Some individuals may react differently to stressful events from others due to their body conditions, age, gender, experience and so on. There are computational

techniques, such as artificial neural network, that can deal with these variables[4]. Additionally, uncertainties and complexities also exists that need to be dealt with when defining stress. Techniques such as, fuzzy logic, can narrow the gap.

Hormon imbalances and physiological and physical changes are some characteristic associated with stress. When a person is under stress, increased amounts of stress hormones (e.g. cortisol or catecholamine levels) are released and measures for these hormones are obtained via invasive methods, possibly performed by qualified practitioners, and require lengthy analysis procedures. Also under stress, changes in heart rate (HR), blood pressure (BP), pupil diameter (PD), breathing pattern, galvanic skin response (GSR), emotion, voice intonation and body pose are observed, which, unlike measuring stress hormones, can be acquired through non-invasive means. This research concentrates on non-invasive and automated measures requiring shorter time periods for detecting and analyzing mental stress. Physiological (e.g. heart rate, skin conductivity) and physical (e.g. facial expressions, voice intonation, body poses, and gestures) features enable such methods and can be used to model stress objectively.

In this research, a measures of stress refers to a primary measure for stress, monitoring stress means examining fluctuations in primary measures for stress, of stress refers to certain fluctuations in primary measures for stress to show an increases in stress towards distress.

The term computed stress is defined as the stress computationally derived from instantaneous measures of stress symptoms obtained by non-invasive methods. A computational model of stress will take some combination of stress symptom measures as

inputs to produce a computed stress measures as an instantaneous measures of stress at that point in time.

Stress research has a wide range of potential applications including the capacity to improve personal, government and industry operations, including increasing the robustness of military operations, law enforcement, athlete performance, games and education software, life support system and commercial products. It also has potential to improve terms using non-invasive techniques that dynamically provide indications of stress that have been exploited to determine stress in fighter pilots[5]. But were to obstructive and do not suits usual terms. However less intrusive systems have been developed to detect stress in range of people including car drivers [6], computers users [7] , army officers, pilots in flight, surgeons and surgical patients.

The current focus of stress research is in determining ways to measure and monitor stress and is in early stages of computational modelling. A range of sensors and techniques from various fields, including computer sciences , engineering and statics have been applied in stress problems. This research will focus mainly on primary measures of stress and computational techniques used for signal analysis, features extraction, stress detection and recognition as well as computational models used in literature over the recent years, and provides a direction for future research.

2. Overview of Internal Estimation of Mental Stress Based on Vision Measurement
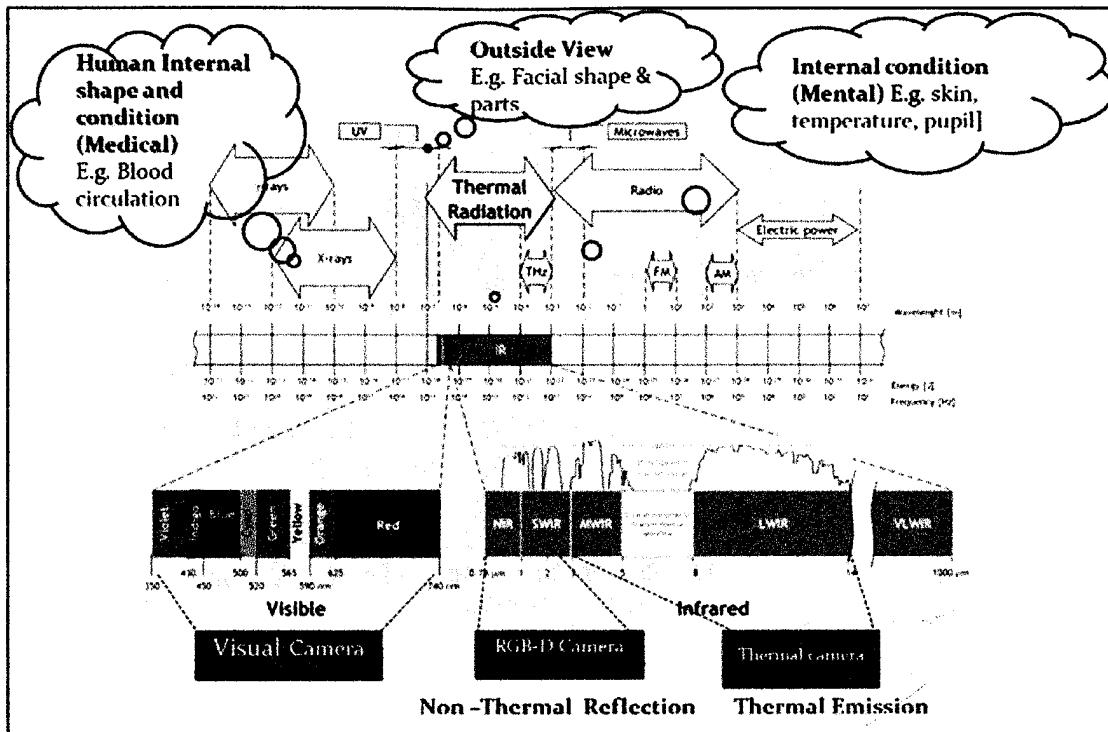
Figure 1.Relationship between optical wavelength and human state observation.

Human state observation can be measured with both visual camera, RGB-D camera from non-thermal reflection and thermal camera when there is thermal emission. Figure 1, shows the relationship between optical wavelength and human state observation. Human external shape can be viewed at the visible optical wavelength from 390 to 700 nm such as facial shape and face parts. Whereas human internal shape and condition (medical) can be viewed using the x-radiation. Most x-rays have a wavelength in the range of 0.01 to 10 nanometers.

The internal conditions on the mental part can be measured at the range of 8-15 μm on the long-wavelength infrared range.

This research objectives are:

(1) To propose and build an accurate and efficient screening environment to be used for monitoring internal emotions mental stress.

(2) To propose and build integrated non-invasive internal emotions (mental stress) measurement through imaging means.

(3) To propose a framework for estimating mental stress.

Table 1: Empirical ranking of primary measures for measuring mental stress

RANK	PRIMARY MEASURE
1	HRV- Heart Rate Variability[4]
2	GSR- Galvanic Skin Response[8]
3	EEG- Electroencephalography[9]
4	PD- Pupil Diameter[10]
5	Voice[11]
6	Eye Gaze[12]
7	Facial Expression[13]
8	BP- Blood Pressure[14]
9	ST- Skin Temperature[15]
10	BVP- Blood Volume Pulse[16]
11	Eye Blinks[17]
12	Respiration[8]
13	EMG- Electromyography[18]

Various methods for internal measurement such as mental stress measurement have been previously proposed which utilizes the changes of physiological through electroencephalography (EEG), blood volume pulse(BVP), heart rate variability (HRV)[19][20], galvanic skin response (GSR) and electromyography (EMG) measurement[21]. However it requires the individuals to wear or touch electrodes or sensors. On the other hand, physical signals for measuring mental stress include eye gaze, pupil diameter, voice characteristic and face movement and these quantities are measured
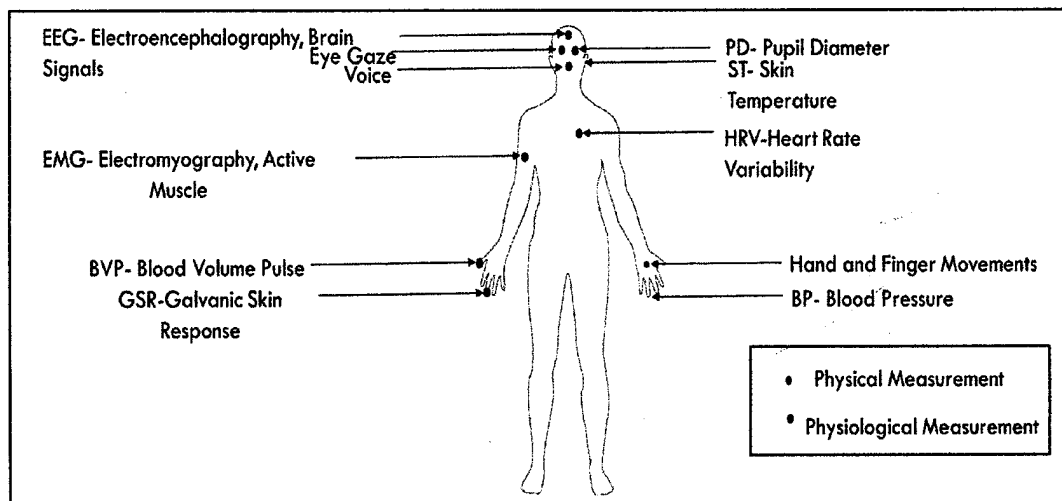
Figure 2: Common Physical and Physiological Measures to detect stress

invasively by the use of expensive instruments. Table 1 , shows the ranking of physiological measurement of mental stress[21]. In this research 3 primary measures that will be considered is ranking no. 1,9,10 and 11. Face recognition system based on visual images have reached significant level of maturity with some practical success. However, the performance of visual face recognition may degrade under poor visual face recognition

system based on visual images have reached significant level of maturity with some practical success. The performance of visual face recognition may degrade under poor illuminations conditions, especially for subject of various skin color and the changes in facial expression. The use of infrared in face recognition allows the limitations of visible face recognition to be solved. However, infrared suffers from other limitations like opacity to glasses. Hence, multi modal fusion comes with the promising solutions.

3. Motivation and Outline of this Thesis

As mentioned above, existing physiological measurement in measuring mental stress is done using expensive measurement tools. Most of the existing physiological measurement is done based on contact measurement where it effects emotions and burden physiologically. Combination of this type of measurement also lead to the collection of redundant and unnecessary large volume of data. This motivates our research study on integrated system and analysis for non-invasive measurement through purely imaging means. In this research, 3 vision-based measurement and 2 physiological measurement were implemented in the system. The thesis is organized as follows.

Chapter 1 describes overview of internal estimation of mental stress based on vision measurement. Background, introduction, importance and purpose of emotion recognition system are elaborated. In recent years various methods for internal state measurement to detect mental stress had been proposed. The problem in the current physiological

measurement is that the combination measures may be redundant with others and this may cause collection of unnecessary large volumes of data and unnecessary processing time. This motivates the use of vision-based as it only requires crucial data after pattern recognition and processing of partial image. Motivation and outline of the thesis is also described in this chapter.

In **Chapter 2**, previous studies and problems of previous method related to vision based measurement are described. The previous work of internal state measurement related to Frequency of eye blinking in visual domain, facial skin temperature of supraorbital, periorbital and maxillary and blood vessel volume at supraorbital in thermal domain are also elaborated. Various types of past mental stress stimulus experiment, stress scale and computational techniques for modelling mental stress is also written in this chapter

In **Chapter 3**, in order to solve those problems mentioned, this study proposed a vision based measurement as an alternative to physiological measurement that is described in this chapter. Our methodology is to estimate emotional state from human subjects by extracting facial characteristic in vision domain which is eye blinking and thermal domain, facial temperature at 3 ROI`s blood vessel volume at supraorbital. Two main topics discussed in this chapter are registration of IR and visible and facial feature extraction in both visual and thermal domain. Three types of registration technique are discussed. Registration of IR-Visible by using fever plaster calibration board, SIFT feature matching and stereo matching by estimation of F matrix.

In **Chapter 4**, in order to verify the effectiveness and the novelty of the proposed research methodology, several experiments are conducted. Experimental setup in this study consist of 3 parts which are experimental setup for vision and physiological sensing, facial feature extraction in visual-thermal domain and experiment on stimulus experiment, data analysis and classification based on Support Vector Machine and emotion recognition system. Two main results are being discussed in this chapter. The first is the result of feature matching and detection in visual and thermal. The second is stimulus experiment and emotion recognition system

In **Chapter 5**, Inadequacies of proposed method and system are analyzed and discussed. Three main problem regarding internal state measurement are also discussed. Ground truth, time variation and individual variation are mentioned. By measuring the relationship of salivary amilase level and pulse rate during the experiment, the ground truth can be verified. In order to overcome the time variation problem, longer and different types of stimulus are proposed. Individual variation are some common problem in internal state measurement and a lot of researchers are working to overcome this problem.

In **Chapter 6**, the conclusion of this study was summarized. The proposed methodology shows promising results because the use of vision based only requires crucial data after pattern recognition and processing of partial image. The proposed techniques to extract facial characteristic to estimate emotional state shows good performance.

Chapter 2

Related Works

1. Introduction

Previous studies and problems of the previous method related to vision based measurement are described in this chapter. The previous work of internal state measurement related to frequency of eye blinking in visual domain, facial skin temperature of supraorbital, periorbital and maxillary and blood vessel volume at supraorbital in thermal domain are also elaborated. Various types of past mental stress stimulus experiment, stress scale and computational techniques for modelling and classification of mental stress is also written in this chapter.
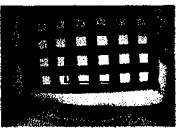
2. Stereo view geometry

References	Collaboration Method	Method	Figure
W. Ursine et.al, "Thermal /visible autonomous stereo vision system calibration methodology for non – controlled environments", QIRT 2012, ID-261, 2012.	High contrast in visible and infrared spectrum, polished copper plate coated with high emissivity paint	Using GPL openCV C++ library,	Figure 2. Laboratory test bench
Dariusz et.al, "Calibration for 3D Reconstruction of thermal Images", QIRT 2008	Special Calibration Board	Using GPL openCV C++ library,	
Stephen Vidas, "A mask based approach for the geometric calibration of thermal-infrared cameras", IEEE IAM 6,2012.	Sized squares cut by hand or cutter and the pattern is held in front of backdrop of thermal radiances such as computer	OpenCV MSER (maximally stable external regions)	

Figure 3:Literature review regarding thermal-visual stereo calibration board

Figure 3 shows several calibration board that was proposed previously by several researchers. Researcher [22], proposed a high contrast in visible and infrared spectrum, polished cooper plate coated with high emissivity paint. [23] propose a special calibration board and set of 2 visual and 1 thermal camera. The thermal camera provides information about temperature distribution on the surface of an examined object. The term 3D reconstruction refers to assigning to each pixel of one of the stereo images a 3D coordinate in the respective camera reference frame. The computed 3D coordinates is the re-projected on the thermography and thus to the known 3D position specific temperature is assigned. [24] proposed a mask based approach for calibration of thermal-infrared cameras. A new geometric mask with high thermal contrast and not requiring a flood lamp is presented as an alternative calibration method. Calibration points on the pattern are then accurately located using a clustering-based algorithm which utilizes the maximally stable external region detector. This algorithm is integrated in to an automatic end-to-end system for calibrating single or multiple cameras.

3. Frequency of eye blinking in internal state estimation.

Figure 4 shows the relationship between blink rates and mental stress. Researcher [25] admits that higher frequency of blinks is detected when individual is under stress . Researcher [12], concluded that lower frequency of blinks results from solving mathematical task. Faster eye closure has been suggested as a characteristic of stress. [26],

concluded that pupil diameter and eye blinks shows promising physiological signal for

affective assessment.

References	Target Area	Relationship/ Method
M.Haak et. al, Detecting stress using eye blinks and brain activity from EEG signals,(DCII 2008),Chez Technical University, Prague	Data from real driving experiment	Higher frequency of blinks is detected when an individual is under stress.
W.Lio, et.al, A real time human stress monitoring system using dynamic Bayesian Network,CVPR,2005	Facial expression, eye movement and head movements extracted from video	Lower frequency of blinks resulted from solving mathematical tasks . Faster eye closure has been suggested as a characteristic of stress
Peng Ren et.al, Affective Assessment of computer users based on processing the pupil diameter signal, IEEE EMBS , August 30-September 3,2014	Data from computer user that analyze his/her pupil diameter.	Pupil diameter and Eyes blink are promising physiological signal for affective assessment.

Figure 4: Relationship between blink rates and stress

4. Facial temperature in Thermal domain

References	Target area	Method	Figure
Kugita et. al, "Research regarding Brain Wave ,Thermal and Internal emotion state ", Watanabe's Laboratory Kagoshima University's Thesis,2011.	Supraorbital & Periorbital	Temperature differences between Supraorbital and Periorbital was measured.	
Dvijesh Shantri et.al " Imaging Facial Signs of Neurophysiological Responses," IEEE Trasc.on Biomedical Eng. Vol.56,No 2 pp 477-484, 2009.	Supraorbital , Periorbital, Maxillary	• 3 ROI was measured, mental task counting circle, • Glass breakage sound and phone ring as acoustic stimulus	
Takahashi Matsuo et.al, "The evaluation of stress intensity through temperature measurement of face", Dynamic and design conferences,08-14,2008.	Periorbital	• 1 ROI measured, thermal face, blood pressure also measured. • Music Listening, typing and arithmetic	
C. Puri, "StressCam : Non-contact Measurement of Users ' Emotional States through Thermal Imaging," Imaging, pp. 1725-1728, 2005.	Supraorbital	1 ROI measured	

Figure 5: Relationship regarding facial temperature in thermal domain.

Figure 5 shows, [27], 3 Region of interest was measured namely supraorbital, periorbital and maxillary. [28], measured only 1 ROI which was supraorbital.
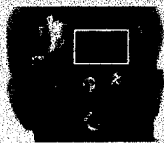
References	Target Area	Relationship/ Method	Figure
Zhen Zu et. al., Forehead Thermal Signature Extraction in Lie Detection, IEEE EMBS ,2007,pp243-246	Supraorbital	Blood flows through supraorbital vascular increase with the increase of stress monitored by MWIR thermal camera	
J.Zail et. al, Stress recognition using non invasive technology, FLAIRS,2006,pp.395-400. S.Reisman, Measurement of psychophysiology and Biofeedback ,33(2008) 83-89	left thumb	Investigation shows that ST negatively correlated with stress when measured at the left thumb. ST has been measured using LM34 IC by placing sensor on the distal phalanx of the left thumb.	

Figure 6:Relationship regarding skin temperature and mental stress

Figure 6, shows the relationship between skin temperature and mental stress.[29] concluded that blood flows through supraorbital vascular increase with the increase of stress monitored by MWIR camera. [30], shows that ST negatively correlated with stress when measured at the left thumb. ST has been measured using LM34 IC by placing sensor on the distal phalanx of the thumb.

5. Blood vessel volume in Thermal domain and Blood pressure

REFERENCES	IMAGE
Generic map of superficial blood vessels on the face (Moxham et. al, 2002)	(a)Overview of arterial network (b)Overview of venous network (c) Arteries and veins together underneath the facial skin.
Pose-Invariant Physiological face recognition in the thermal Infrared spectrum, P.Buddharaju et. Al, CVPRW 2006	
Face Recognition Beyond the visible spectrum, P.Buddharaju et. al, Advances in Biometrics, 157-180	Fig. Minutia points extracted from branches of facial vasculature (MWIR)
Zhen Zu et. al., Forehead Thermal Signature Extraction in Lie Detection, IEEE EMBS ,2007,pp243-246	Fig. Vessel Tracking and segmentation result (MWIR)

Figure 7:Relationship regarding blood vessel detection at supraorbital.

Figure 7 shows the relationship regarding blood vessel detection at thermal domain.[31], proposed the technique to detect blood vessel on MWIR facial image by using anistropically diffused image and top hat segmentation. [32], proposed how minutia points extracted from branches vasculature.[29], proposed on how to do vessel tracking and segmentation at forehead area.

References	Target Area	Relationship/Method	Figure
Zhen Zu et. al., Forehead Thermal Signature Extraction in Lie Detection, IEEE EMBS ,2007,pp243-246	Supraorbital	Blood flows through supraorbital vascular increase with the increase in stress monitored by MWIR thermal camera.	
T.Pickering et.al., Environmental influences on blood pressure and the role of job strain, Journal of ISH 14(1996), 179-185	Finger arterial	An increase of BP have shown correlation with increase in stress, monitored by Finger arterial Pressure	
S.Reisman, Measurement of psychophysiology and Biofeedback ,33(2008) 83-89	Finger	Decrease of BVP (blood volume in a blood vessel during certain time interval) correlate with increase of stress, measured by Photoplethysmography (PPG)a skin capillary bed of a finger.	

Figure 8. Relationship between blood vessel volume and blood flows

Figure 8, shows the relationship between blood vessel volume and blood flows.[29], blood flows through supraorbital vascular increase with the increase of stress monitored by MWIR thermal camera.[33], claimed that an increase of blood pressure at finger arterial in correlation with increase of stress monitored by finger arterial pressure.[33], S.Reisman et.al, mention decrease of BVP volume in a blood vessel during

certain time interval correlate with increase of stress, measured by PPG a skin capillary bed of finger.

6. Types of stimulus experiment, stress scale and computational techniques of mental stress recognition.

Table 2: Stress scale

Stress Scale	Referances
1. Stressed or relaxed	Jing Zhai et.al, IEEE EMBS USA, Aug 30- Sept 3,2006
2. Low, Medium and High	J.A.Healey, R.W.Picard, Detecting stress during real world driving task using physiological sensors, IEEE ITS 2006,156-166.
3. No-stress, Average and High Stress	Z.Dharmawan, Analysis of Computer games player stress level using EEG data, Master Thesis, Delft Univ. 2007
4. Continuous scale of 0-100	M.Kumar et.al ,Fuzzy evaluation of Heart rate signals for mental stress assessment, IEEE Transactions on fuzzy Systems 15(2007),791-808
5. Time varying Scale (Stress scale over time)	

Table 2, shows the stress scale proposed by several researchers. [30], proposed 2 types of classification stressed or relaxed. [33] and Z.dharmawan, proposed three level scale which is low, medium ,high and no-stress, average and high stress . M.Kumar et. al. also proposed 0-100 scale for stress measurement. In this research, we are trying to propose a time varying scale.

Table 3: Various types of mental stimulus stress experiment

Mental Stress Stimulus	References
Stroop Color word Interference test	Jing Zhai et.al, IEEE EMBS USA, Aug 30- Sept 3,2006
Video games	Lin et. al , CHISIG AUSTRALIA, 2005
Diver and Pilot Simulation	Picard et.al , Wearable and automotive systems for affect recognition from phsiocology, Technical report, MIT,2000
Hyperventilation and talk preparation	De Santos Sierra et.al, Industrial Electronics, IEEE Transactions on PP,2011
Glass breakage sound and phone ring as acoustic stimulus	Dvijesh Shantri et.al " Imaging Facial Signs of Neurophysiological Responses," IEEE Trasc.on Biomedical Eng. Vol.56,No 2 pp 477-484, 2009.
Music Listening, typing and arithmetic	Takahashi Matsuo et.al, "The evaluation of stress intensity through temperature measurement of face", Dynamic and design conferences,08-14,2008.

Table 3 shows various types of mental stimulus stress experiment.[27], proposed glass breakage sound and phone ring as acoustic stimulus. [34], using music listening, typing and arithmetic as a stimulus.[35], using pilot simulation as stimulus for pilot.[36], proposed the use of stroop color word interference test as a stimulus.

Table 4, shows computational techniques for modelling mental stress.[37], reported an

Table 4:Computational techniques for modelling mental stress

RANK	MODELLING TECHNIQUES	REPORTED ACCURACY	INPUT FOR MODELS	REFERENCE
1	SVM	90.10%	GSR,HR,PD,ST	(J.Zail ,et. al, Stress recognition using non invasive technology,FLAIRS,2006,pp.395-400.)
2	Recurrent ANN	MSE=0.0084	Voice	(S.Scherer, et. al, Emotion Recognition from speech: stress experiment,LREC,2008)
3	Adaptive neuro-fuzzy system	76.7%	EMG,ECG	(C.D. Katsis, et. al, Toward Emotion recognition in car-racing drivers, IEEE,System and Humans 38(2008)1238-1246)
4	ANN	82.7%	EEG	(S.A. Hosseini, Emotional Stress recognition system using EEG and psychophysiological signals,ICBECS,2010,pp.1-6)
5	HMM	Not Provided	Voice	
6	Decision Tree	88.02%	GSR,HR,PD,ST	(J.Zail ,et. al, Stress recognition using non invasive technology,FLAIRS,2006,pp.395-400.)
7	Naive Bayesian Network	78.65%	GSR,HR,PD,ST	(J.Zail ,et. al, Stress recognition using non invasive technology,FLAIRS,2006,pp.395-400.)
8	Fuzzy Clustering	Not Provided	HRV	

accuracy of 82.7% when using Artificial Neural Network as a modelling techniques and

EEG as an input for models.[38], proposed modelling techniques based on adaptive neuro fuzzy system based on EMG and ECG as input and reported an accuracy of 76.7%.[39], proposed recurrent ANN and the input was voice and the accuracy that was reported was 84%.[30], reported and accuracy of 90.10% using SVM and GSR,HT,PD and ST as an input.

Chapter 3

Proposed Method

1. Introduction

In this chapter, an integrated non-invasive measurement via imaging techniques is proposed. The main aim is to propose a vision-based measurement as an alternative to physiological measurement. The fusion of physiological vision-measurement from thermal IR and visual is shown in Figure 9 and 10 . Our research consists of three vision based physiological measurements which are eye blinking from visual sensor, skin temperature of 3 ROI's and blood vessel volume at supraorbital from thermal IR camera. The primary physical measurement in detecting mental stress is heart rate variability [21] and salivary amylase level [40] as proof by earlier researcher. The normal heart rate ranges from 60-100 bpm. In other hand, salivary amylase level [40] increased significantly and is suggested as the better index of mental stress. Salivary amylase with level more than 60 $KU\backslash L$ is considered to have mental stress. Both of the measurement was used as a ground truth measurement in our research. The data set consisting the proposed vision measurement is attached. In this chapter, a new calibration chessboard attach with fever plaster to locate calibration point in stereo Visual-Thermal view is proposed. A new method of integration of two different sensors for detecting facial feature in both thermal and visual is also presented by applying nostril mask, which allows one to find facial feature namely nose area in thermal and visual domain. In this chapter also three ways to compute the relationship between visible-IR camera is explained.
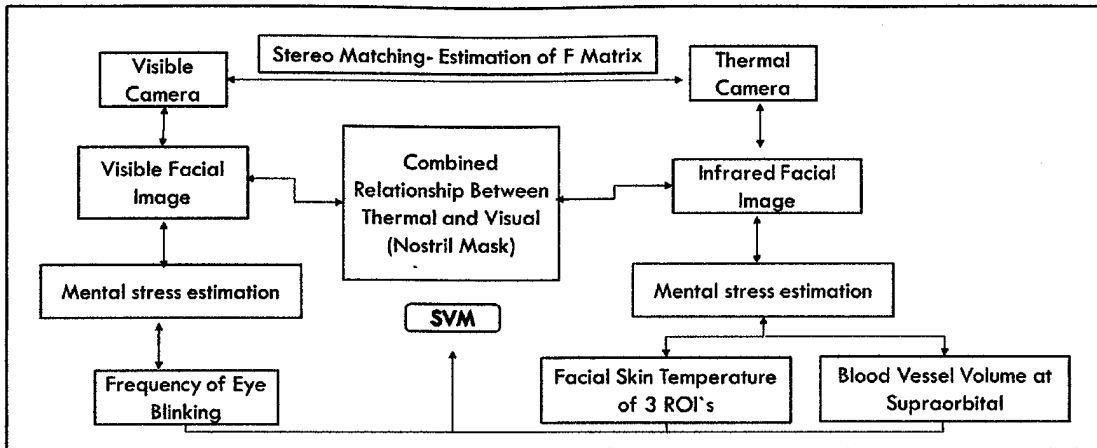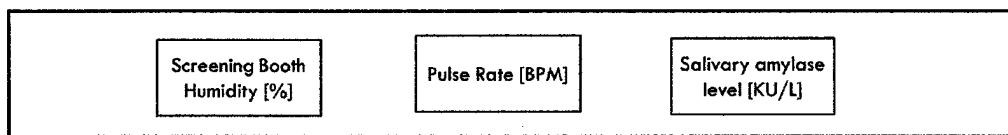
Figure 9:Overall vision based measurement

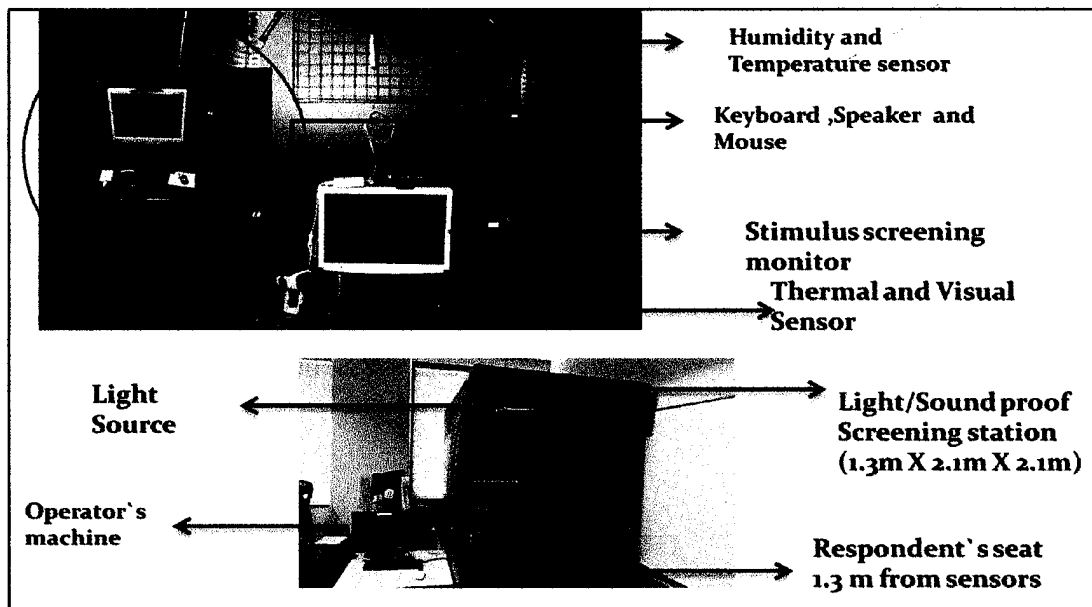**Figure 10: Physiological based measurement (ground truth)**

Figure 11: Screening station

2. Registration of IR and Visible Camera

This study propose three ways to compute the relationship between Visible –IR camera as below.

1.0 Registration of IR-Visible by using fever plaster calibration board.

The relative position between IR and visible cameras is calibrated by using the special calibration board suggested below. The relative position between thermal-visible stereo cameras is calculated using the heated calibration board which is due to the emissivity difference between the black and white squares on the grid. The output of the calibration method includes the relative rotation and translation of the cameras as well as the internal parameters. One of the common strategies to simplify correspondence problem between IR and visible domain is to exploit epipolar geometry [41][42][43]. The relative position between thermal-visible stereo cameras is calculated using the heated calibration board (Fig.12) which is due to the emissivity difference between the black and white squares on the grid. The output of the calibration method includes the relative rotation and translation of the cameras as well as the internal parameters.
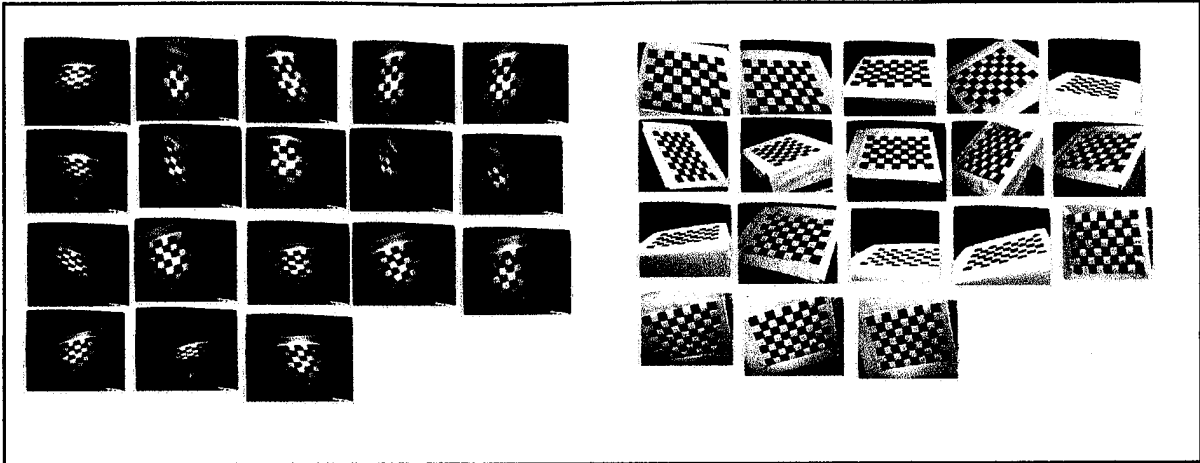
Figure 12:Proposed Stereo checker board 14 left-right

the cameras with respect to the left hand view and the internal parameters of each camera, focal length f_c, principal point c_c ,skew coefficients α_c and radial and tangential distortion k_c.Following stereo calibration, coordinates of a 3D point, $p_{c=}[x_c,\ y_c, z_c]$ as follows $P_c = T + RP$, where R and T are their respective relative rotation and translation with respect to the world coordinates. Here, for the surface reconstruction procedure , we make use of the image point projection of the scene normalized so as to follow the pinhole camera model [10], Let the normalized (pinhole) image projection, $p_n = [x, y]$ be given by:

$$p_n = \begin{bmatrix} x_c/y_c \\ y_c/y_c \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix}.$$

[1]

After including the lens distortions, the new normalized point coordinates $p_d = [x_d, y_d]$ is obtained

$$p_d = \begin{bmatrix} x_d \\ y_d \end{bmatrix} = (1 + \mathrm{kc}(1)r^2 + \mathrm{kc}(2)r^4 + kc(5)r^6)p_n + \mathrm{dx}$$

[2]

Where $r^2 = x^2 + y^2$, and dx is the tangential distortion vector

$$d_x = \begin{bmatrix} 2kc(3)x + kc(4)(r^2 + 2x^2) \\ kc(3)(r^2 + 2y^2) + 2kc(4)xy \end{bmatrix}$$

[3]

With these ingredients, we can relate the normalized coordinate vector, p_d, and the pixel image coordinates, x_d and y_d as follows

$$\begin{bmatrix} x_p \\ y_p \\ 1 \end{bmatrix} = K \begin{bmatrix} x_d \\ y_d \\ 1 \end{bmatrix}$$

[4]

Where K is known as the camera parameter matrix, which can be expressed making use of the calibration output variables as

$$K = \begin{bmatrix} f_c(1) & \alpha_c * f_c(1) & cc(1) \\ 0 & f_c(2) & cc(2) \\ 0 & 0 & 1 \end{bmatrix}$$
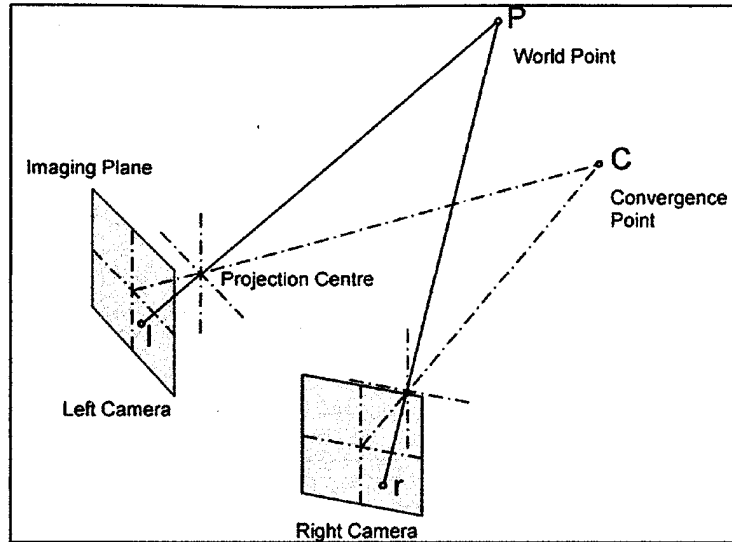
[5]

Figure 13:Stereo view geometry

In a two perspective views, each view has an associated camera matrix as P, P' , where '

indicates entities associated with the second view, and a 3-space point **X** is imagined as

x=P**X** in the first view , and x`= P`**X** in the second. Image points x and x` correspond

because they are the image of the same 3-space point. There are three questions that will

be addressed in stereo view[44][41][43]:

1. Camera Geometry (motion): Given corresponding image points $\{ x_i \leftrightarrow x'_i \}$,

   i=1,....,n, what are the cameras P and P' for the two views?

2. Correspondence Geometry (stereo matching): Given an image point in x in the first

   view, how does this constrain the position of the corresponding x' in the second

   view?

ACKNOWLEDGMENT

REFERENCES
[1] L. Pavlidis, J. Levine and P.Baukol," Thermal imaging fro anxiety detection,"Proc. IEEE Workshop Computing Visual beyond Visible Spectrum: Methods Appl. 2000, pp. 104-109.

[2] L.B.Wolff, D.A. Socolinsky and C.K.Evel ,"Quantitative measurement of illumination invariance fro face recognition using Thermal Infrared Imagery "in Proc.SPIE Vol 4820, Inferred Technology and Applications XVIII,B.Andresen ,G.F.Fulop,M. Stronmjnik.Eds.Jan 2003,pp.140-151.

[3] Z.Zhang,"A Flexible New Technique for camera calibration", IEEE Trans. Pattern Anal. Mach. Intell., Vol.22, no. 11, pp. 1330-1334, Nov.2000.

[4] Prakash S.,.Lee P.Y.,Caeli T.,and Raupach T.," Robust Thermal camera calibration and 3D mapping object surface temperatures".Thermosense XXVIII, 6205:62050J1-62050J8.2006.

[5] Hartley R. and Zisserman A., "Multiple view geometry in computer vision". Cambridge University Press, 2000.

[6] Koschan A., "What is a New in Computational theory since 1989: A survey of current stereo paper."Technical Report, 93-22, 1993.

[7] Faugeras O., "Three Dimensional Computer Vision: A geometric Viewpoint". The MIT Press, 1993.

[8] InterSense Inc, InertiaCube [Online] www.intersense.com

[9] H.enno.A.Saijo, H.yoshida, R.Suzuki and M. Osumi,"Using Facial temperature to objectively evaluate sensation"Inter. Journ. Ind. Ergonomics, Vol. 19, no 2, pp161-171 Feb. 1977.

[10] H.enno.A.Saijo, H.yoshida, R.Suzuki and M. Osumi," Non- contact method for measuring facial skin temperature", Inter. Journ. Ind. Ergonomics, Vol. 19, no 2, pp147-159 Feb. 1977.

[11] Jian-Gang Wang," Facial Feature Extraction in an infrared Image by Proxy with a Visible Face Image"IEEE Transc. On Instrumentations and Measurement, Vol 56, No 5, pp 2057-2066, Oct. 2007.

[12] P.Viola and M.Jones,"Robust real time object detection". Inter.Journal of Computer Vision, Vol.57, No 2, 2002.

[13] C.Puri,L.Eberhardt and J.Levine," StressCam:Non- Contact measurement of users' emotional states through thermal imaging."inProc. Of ACM Conf. Hum. Factors Computing System (CHI), 2-5, 2005. pp.1725-1728.

[14] J.Levine, I.Pavlidis, and M.Cooper," The face of Fear", Lancet, vol. 357, no 9270, p.1757, Jun 2001.

[15] I.Pavlidis, N.L. Eberhardt and J.Levine." Human Behaviour: Seeing through the face of deception", Nature, vol.415, no 6867, p.35, Jan.2002.

[16] Dvijesh et.al. "Imaging Facial Signs of Neurophysiological Responses"IEEE Transactions on Biomedical Engineering Vo.56, No.2, February 2009.

[17] Qui Jin et. Al."Facial Feature Extraction with a Depth AAM Algorithm", Inter. Conf. on Fuzzy System and Knowledge Discovery (FSKD 2012), 1792-1796.