Issue 9 vol 3 ISSN: 2321-8134

IJFEAT

INTERNATIONAL JOURNAL FOR ENGINEERING APPLICATIONS AND TECHNOLOGY

HYPERSPECTRAL IMAGING IN THE FIELD OF STRESS DETECTION

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Abstract

With the growing industries, workload is also increasing which is giving way to increase in stress level of humans. In this condition, the detection of stress at early stages is beneficial to both individuals and communities. However, traditional stress detection methods that use physiological signals are contact-based and require sensors to be in contact with test subjects for measurement. In this seminar, present a method to detect psychological stress in a non-contact manner using a human physiological response. In particular, utilizes a hyperspectral imaging (HSI) technique to extract the tissue oxygen saturation (StO2) value as a physiological feature for stress detection. HSI collects and process information from across the electromagnetic spectrum. HSI for STO2 assessment works on a Beer-Lambert law. Along with tissue oxygen saturation, Saliva Cortisol and Heart Rate also utilized as a secondary indicators for stress. Trier Social Stress Tests (TSSTs) on some healthy volunteers demonstrated a significant difference and a large practical discrimination between normalized baseline and stress StO2 levels. TSST involves some sub-tests and for each sub-test, HSI data is recorded as sets of images. With the elevation in Heart Rate, HSI data is gets recorded with the purpose to decrease the load on computing system. Galvanic Skin Response is very useful for detecting emotion of the participants. These results suggest that the StO2 level could serve as a new modality to recognize stress at standoff distances.

Index Terms: *Stress detection, hyperspectral imaging, remote sensing, tissue oxygen saturation etc.*

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1. INTRODUCTION

Human stress represents an imbalanced state of an individual and is triggered when environmental demands exceed the regulatory capacity of the individual. Because of its unhealthy effects , stress detection is an ongoing research topic among both psychologists and engineers and has been applied to lie detection tests , emergency call identification, and the development of better human computer interfaces . Various features associated with stress, including hormone responses, physical appearance, speech, and physiological responses, have been utilized for stress detection. Among these stress features, physiological responses are attracting an increasing amount of attention . However, traditional physiological-based detection methods are contact methods, i.e., sensors must be attached to individuals during feature measurement, which is not convenient. In this paper, we propose a non-contact detection method that uses a physiological signal. This method enables measurement of a physiological feature at standoff distances, which offers more comfort for test subjects and more covertness for testers. Specifically, our method uses a hyperspectral imaging (HSI) camera to obtain tissue oxygen saturation (StO2) data as a feature for detecting human stress. This study reported that, HSI could be a promising technique for remotely sensing human stress. In this paper, we elaborate on the experiment design, explain why StO2 was chosen as a stress indicator, present statistical test results, and develop a stress index (SI) to detect psychological stress that is independent of baseline information.

2. HYPERSPECTRAL IMAGING

HSI is a technique which collects and process information from across the electromagnetic spectrum. HSI enables the imaging of a scene in hundreds of contiguous, narrow wavebands, with a bandwidth of approximately 10 nm and in the visible and infrared regions of the electro-magnetic spectrum, to form image cubes with both spatial and spectral dimensions. Every pixel within the image cube is associated with three coordinates: namely, two spatial coordinates (x,y), which represent the location of pixels in 2D space, and one spectral coordinate, which represents the wavelength. Each pixel in the image cube represents the extent of light reflected by the object in the scene within a narrow slice of wavebands across the whole spectrum, up to the sensitivity limits of the camera. If the intensity of the reflected light is normalized to the incident light intensity for each image pixel, a characteristic reflectance spectrum of the object in the scene can be obtained.

This technique is very different compared with conventional photography, in which three broad color channels (R,G,B) with wavebands on the order of 100 nm are probed. The integration of spectral characteristics over broad wavebands tends to reduce the color discrimination ability in conventional photography. For this reason, HSI uses a narrow bandwidth for spectral sensing and has been one of the fastest growing technologies in electro-optics in the 20th century. The classification of objects in a scene can be performed using textural features (e.g., shape, orientation, and intensity variation) from a slice of a spectral image or in combination with features selected from a subset of spectral images across different wavebands. Its power of material discrimination is the reason why HSI is used as the primary technique in this research. One requirement of this work is to sense and distinguish blood chromophores from body tissues; the amount of oxygenation within the blood is subsequently quantified using an optical absorption model.

Fig-2.1 : HSI Image Cube

3. STRESS AND StO2

3.1 StO2

When air is inhaled into the lungs, oxygen binds to hemoglobin through an unstable and reversible bond that forms oxy-hemoglobin (HbO2). HbO2 complexes appear bright red in color and are transported to every part of the body through arterial blood vessels and capillaries. After the oxygen has been consumed by cells and tissues, the HbO2 complexes are decomposed into deoxy-hemoglobin (Hb) complexes, which exhibit a purple-blue color, and are returned to the heart through the venous blood vessels and, subsequently, to the lungs. The next cycle of Hb binding to oxygen to form new HbO2 complexes subsequently begins. Each haemoglobin molecule is capable of binding up to four oxygen molecules. If all four binding sites of each haemoglobin molecule are occupied with oxygen molecules, the oxygen saturation of haemoglobin is 100 percent. However, blood leaving the lung normally has a haemoglobin oxygen saturation range of 90-100 percent, depending on the individual and the situation.

Haemoglobin oxygen saturation (SO2) is defined as the ratio of the amount of HbO2 to the total amount of haemoglobin :

SO2 = HbO2 / Hb+HbO2

Arterial blood exhibits a relatively strong HR pulsation, and its SO2, which is called the arterial oxygen saturation, is most often measured using the pulse oxymetry technique. Arterial oxygen saturation is fairly constant and varies from 90-99 percent in healthy individuals. StO2 is the SO2 of the microcirculation in tissue and ranges from approximately 60 percent for venous SO2 to 98 percent for arterial SO2.

3.2 Arousal of Tissue Oxygenation

Adrenaline is secreted through the hypothalamic-pituitaryadrenal axis in response to a stressor. It binds to the adrenergic receptors of peripheral tissues, which prepare the body for the fight-or-flight response :

- Acceleration of heart and lung actions
- Liberation of nutrients, such as glucose and oxygen, for muscular action.
- Increase in blood pressure and stickiness
- Redirection of blood to provide the highest perfusion and fuel to the aroused brain, heart and muscles.

These responses substantially increase the StO2 and tissue oxygen content. The effects increased superficial blood flow (1-2 mm below the skin surface) on the human facial region upon the onset of a psychological stressor was recently reported. The mean blood flow (measured by laser Doppler flowmetry or photoplethysmography) of the forehead and cheek during the stressed state increases, which reveals that the StO2 of these regions is affected by the stress or the hormones secreted along with the stress.

4. HSI ORIENTATION

HSI is an emerging technique used to remotely sense StO2 in vitro, and the results can be presented in a spatial 2DStO2 map. Substantial efforts in the field of HSI StO2 assessment have been based on the Beer-Lambert Law, which relates the absorption of light to the properties of the material through which the light is travelling:

A=€*l*c

where A is the absorbance, defines the molar extinction coefficient $cm^{-1}(mol/L)^{-1}$ (or molar absorbtivity) of the material, c represents the molar concentration (mol=L) of the absorber, and l denotes the distance (cm) travelled by the light through the material. In an HSI reflectance model, the path length l is difficult to measure. The product lc in equation is thus reduced to Ceff , the effective concentration (10^{-3} mol/cm^2), which represents the molar concentration of absorbers per unit area.

5. EXPERIMENTAL SETUP

The HSI system utilized in this research consisted of a VNIR spectrograph combined with a RIKOLA hyperspectral camera and a home-designed mirror scanning system. The slit of the spectrograph was 30 mm wide, which provided a maximum spectral resolution of 5 nm. The spectral sensitivity limit of the camera ranged from 400 to 1,000 nm. The opening angle of the camera was 30 degree. The dimensions of the entire HSI system were approximately 40*40*15 cm. Broad-band halogen lamps were used throughout the imaging process as illumination sources. A cheststrap heart monitor was used to monitor the HR of each subject during the experiment and Galvanic Skin Response also been used. The HSI system took pictures using a fixed number of wavelengths, which ranged from 400 to 1,000 nm in 2 nm steps (300 wavelengths). This system required 10 s (integration time 40 ms, 250 scanning lines) to record one image cube. The StO2 measurements result from the still images of the objects. The HSI system used in this research cannot operate in real-time. However, by using a more-sensitive HSI system (integration time can be 5 ms) with the ability to image a flexible number of wavelengths, such as an acoustic-optic tunable filter-based HSI system with scientific CMOS or electron multiplying CCD sensors, the image cube could be obtained in approximately real-time (8 fps, if 30 wavelengths within 520-580 nm were used).

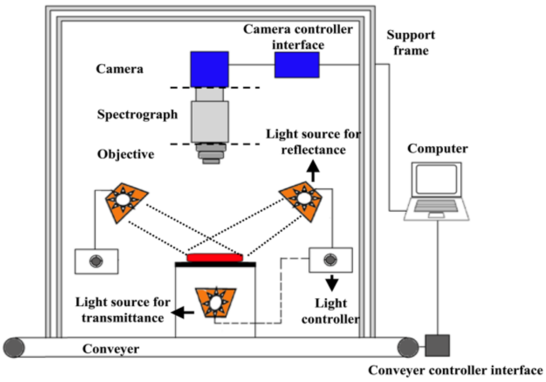

Fig.-5.1 : HSI Setup

6. TSST

6.1 Psychological Stressors

The TSST is designed to exploit the vulnerability of the stress response to socially evaluative situations. In this test, some healthy volunteers of different career background are considered. The period of induced stress lasts approximately 15 minutes, and is divided into 5 minute components. Before the test begins, the participant is fitted with a heart rate monitor and Galvanic Skin Response. Stress induction begins with the participant being taken into a room where a panel of three judges are waiting, along with a HSI setup. Participant have to sit calmly and HSI data is recorded as a baseline data. The first 5 minute component is the anticipatory stress phase, during which the judges ask the participant to prepare a 5 minute presentation. In most studies this presentation is framed as part of a job interview. Also, the judges have been trained to maintain neutral expressions throughout the test. The participant is allowed to use paper and pen to organize their presentation, but this paper is then unexpectedly taken away from them when it is time to begin the presentation. During the 5 minute presentation component, the judges observe the participant without comment. If the participant does not use the entire 5 minutes, they will ask him or her to continue. This goes on until the entire 5 minutes have been used. The presentation is immediately followed by the mental arithmetic component, during which the participant is asked to count backwards from 1,022 in steps of 13. If a mistake is made, then they must start again from the beginning. This component lasts for 5 minutes and is followed by a recovery period. Saliva and Heart Rate continue to be collected after the stress induction period has ended. HSI data is recorded after each test.

6.2 Saliva Cortisol and HR as Indicators of Stress

Cortisol is a reliable biomarker for acute psychological stress . Therefore, saliva cortisol served as an accurate basis to judge whether the stress response was activated in this study. The participants' cortisol levels at baseline and after each stress testing cycle were compared. Only when a participant's stress cortisol level increased to at least 125 percent of his/her baseline cortisol level could he/she be regarded as a successfully stressed participant, and his/ her HSI data at the end of the stress test were used for subsequent analyses. A small cotton swab of a salivette was provided to each participant prior to conducting the stress test (baseline) and retrieved after the test. However, during the stress test, we could not judge whether the participants were experiencing the stress response by analyzing their cortisol level; this analysis was performed after testing. HR elevation served as an indicator for recording and monitoring HSI data throughout testing. A rise in HR was presumed to indicate that a participant was stressed, and his/her HSI data recording was initiated when a continuous rise in HR was observed from the previous time point and when his/her HR was at least 6 beats per minute (bpm) higher compared with the HR at the beginning of the test .

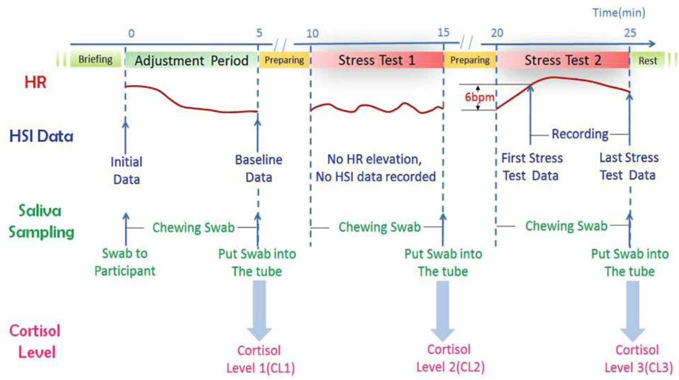

Fig. 6.1-Experimental Recorded Data

6.3 Facial StO2 & Stress Detection

The StO2 results indicated that all participants exhibited an increase in StO2 level in the facial region, particularly in the forehead region, when subjected to a psychological stressor. Figs. 7.2a and 7.2b show the facial StO2 maps of participant A at baseline and when a psychological stressor was experienced, respectively. Participant exhibited an increase in tissue oxygenation in the facial region, particularly in the forehead and eye socket regions, when a psychological stressor was experienced. This facial StO2 elevation was observed in all participants when stress was experienced.

The forehead ROI used to calculate the average StO2 levels was the forehead center region (i.e., from the end of the left eyebrow to the end of the right eyebrow and from the top of the eyebrows to 2/3 the distance from the top to the bottom of the head), which is highlighted in Fig. 7.3 with a black rectangle. The average ROI StO2 values as well as the standard deviations, rates of StO2 increases, HR increases, cortisol increases as a result of the stressors. All HRs and cortisol levels of the participants increased, which ranged from a minimum elevation rate of 4.41 percent for HR and 15.49 percent for cortisol to a maximum of 32.33 percent for HR and 195.28 percent for cortisol ; these findings indicate positive responses to the stimulations from all participants.

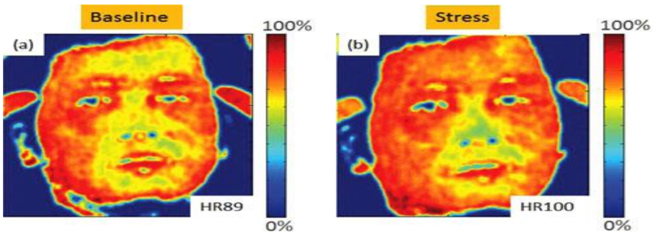

Fig. 6.2 - StO2 maps of participant (a) at baseline and (b) when psychological stress was experienced

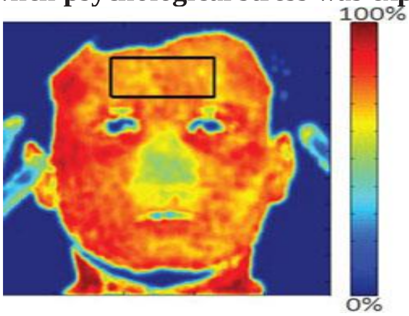

Fig 6.3 - Region of interest on the forehead for generating the average and standard deviation StO2 values.

8. CONCLUSION

In this seminar, we have presented an HSI-based method for the detection of psychological stress. The manner in which HSI signals are obtained (captured image) characterizes this method as a contact-free stress detection technique. Facial StO2 is proposed as a feature for stress detection. We have observed that StO2 is elevated not only around the eye socket area but also around the forehead when individuals respond positively to a psychological stressor. The results suggest that the HSI StO2 can serve as a new modality to recognize stress at standoff distances. Thus, HIS shows the real-time processing substantially depends on a high performance computing system. HR was used as an indicator to record HSI data in this research. Without an HR reference, the HSI data would have been continuously recorded, thereby increasing the computing load. The real time processing of HSI substantially depends on a high performance computing system. A system capable of non-contact HR monitoring combined with the HSI system would be better-suited for stress detection compared with the HSI system alone.

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