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APPLICATION NOTE

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Application Note 276: **Emotional State Recognition via Physiological Measurement and Processing**

This application note is concerned with the implementation details for determining emotional state based on three physiological measures.

EMG recording hardware: BN-EMG2, EMG100C, or MP36/36R: 2 analog CH inputs
EDA recording hardware: BN-PPGED, EDA100C, or MP36: 1 analog CH input

Theories of Emotion

The James-Lange Theory of Emotion

Emotions occur as a result of physiological reactions to stimuli. Emotional state depends on how the subject interprets their own reaction to any specific event.

The Cannon-Bard Theory of Emotion

Physiological reaction and emotional state occur simultaneously. Emotions occur when the thalamus activates the central nervous system (CNS) in response to stimuli, which results in physiological reaction.

Schachter-Singer Theory of Emotion

In response to stimuli, a physiological reaction occurs. To experience the reaction and categorize it as a specific emotion, the subject is required to identify the reason for their specific reaction.

Affect and Emotion Relationship

Affect is the observable (measurable) expression of emotion. When subjected to stimuli, the nervous system is affected. An emotional state may result from stimulation and that state may be indirectly assessed via affect. Affect results from different components of the nervous system expressing in the body.

Nervous System Components

The CNS includes the brain and spinal cord. The peripheral nervous system (PNS) connects the CNS and the body. The PNS consists of two parts, the autonomic nervous system (ANS) and the somatic nervous system (SoNS). The SoNS mediates voluntary control of body movements.

The ANS regulates fundamental physiological states that are typically involuntary, such as heart rate, digestion, and perspiration. The ANS is largely responsible for maintaining the equilibrium of the body's systems. The ANS is connected to smooth muscles, cardiac muscle tissue, and the secretion glands of organs.

The ANS comprises three components, the sympathetic nervous system (SNS), parasympathetic nervous system (PsNS), and enteric nervous system (ENS). The SNS and PsNS work in an opposing manner to maintain the internal equilibrium of the body. Affective stimuli can have a significant effect on ANS activity, and many physiological signals reflect the activity of the ANS. The SNS functions in circumstances that require quick responses. The PsNS functions in circumstances that do not require immediate responses. As SNS activation increases, then PsNS activation decreases and vice-versa.

SNS Activation Result Increases

Adrenal function (boosts cortisol, epinephrine, and norepinephrine)
Blood pressure
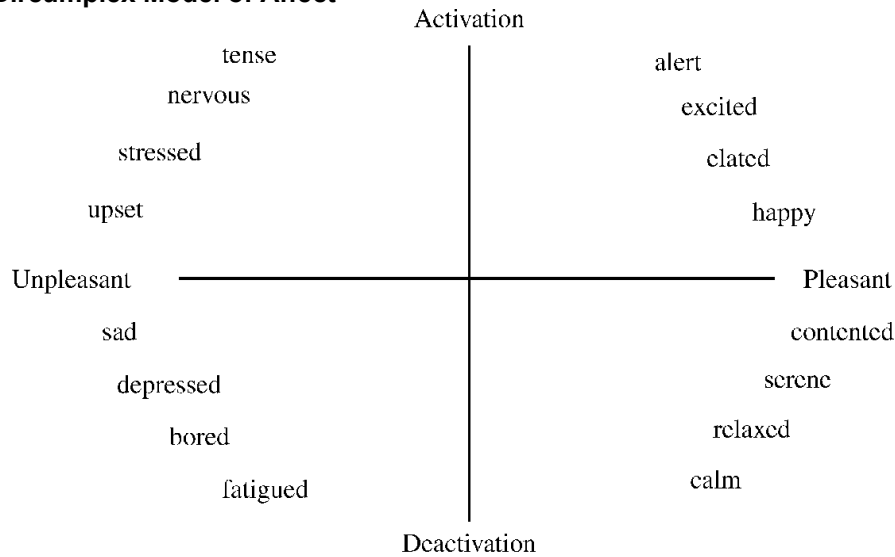Clotting (blood)
Dopamine release
Eye pupil size

Glucose (fuel) utilization
Heart rate
Metabolites (e.g., glucose)
Oxygen circulation
Sweat secretion

PsNS Activation Result Increases -

Defecation
Digestion
Glucose (fuel) storage

Salivation
Secretion of tears
Urination

Circumplex Model of Affect

Activation

tense	alert
nervous	excited
stressed	elated
upset	happy

Unpleasant ———————————————————————— Pleasant

sad	contented
depressed	serene
bored	relaxed
fatigued	calm

Deactivation

Affective states arise from the behavior of two independent neurophysiological systems, the activation (arousal) and valence systems. Affective states are a function of these two systems.

The circumplex model is two-dimensional, with activation and valence defined as orthogonal (perpendicular) axes.

- The *activation* axis, plotted vertically, ranges from deactivation (zero arousal) to activation (high arousal).

- The *valence* axis, plotted horizontally, ranges from negative to positive.

Source: Feldman-Barrett and Russell (1998)
Both arousal and valence levels can be estimated by sensing aspects of physiological state.

Some Physiological Signals Used to Determine Emotional State

1. **Skin Temperature (SKT)** - Skin temperature changes are primarily driven by variations in blood flow. These local variations are mainly caused by changes in vascular resistance or arterial blood pressure. Local vascular resistance is modulated by smooth muscle activity, which is mediated by the SNS. SKT variation reflects SNS activity and is an indicator of emotional state.

2. **Heart Rate** - The sino-atrial (SA) node is the pacemaker of the heart. The SA node receives inputs from both the SNS and PsNS. The SA node can be considered a spike-train generator whose inter-spike (firing) interval is modulated by both SNS and PsNS activity levels. Because both SNS and PsNS activity influence SA node spike firing, heart rate behavior can be considered dependent on emotional state. SNS activity increases heart rate and PsNS activity decrease heart rate.

   Heart rate variability (HRV) is a measure of heart rate changes over time. HRV has a frequency range of 0.05 to 4Hz. PsNS influences occur over the total frequency range of HRV. SNS influences drop off at about 0.15 Hz. High frequency HRV (HF-HRV) is an indication of HRV power in the range of 0.15 to 4Hz and represents primarily PsNS influences. Low frequency HRV (LF-HRV) is as indication of HRV power in the range of 0.05-0.15Hz and represents both SNS and PsNS influences. PsNS influences can affect heart rate in a fraction of a second, but SNS influences can only affect the heart rate after a few seconds. Accordingly, PsNS influences are uniquely capable of producing high-speed changes in the heart rate.

   PsNS innervation of the heart is controlled by the right vagus nerve via the SA node. PsNS induced changes in heart rate are associated with vagal nerve activity that is modulated by respiration. Expiration causes an increase in vagal nerve activity, so heart rate decreases. Inspiration causes suppression of vagal nerve activity, so heart rate climbs back up.

   This combined action is known as respiratory sinus arrhythmia (RSA). RSA is considered, in part, to be an index of emotional regulation. Total HRV appears to be positively correlated with valence. When attention increases, there is a short-term deceleration of heart rate. Arousal is also correlated to a long-term acceleration in heart rate. Heart rate also provides an indication of valence. Compared to neutral stimuli, both positive and negative stimuli first exhibit a short term decrease in heart rate. Over the long term, positive stimuli are correlated with an increase in heart rate while negative stimuli usually are correlated to a decrease in heart rate.

3. **Respiratory Rate** - Respiratory activity occurs via periodic contraction and relaxation of respiratory muscles, including the diaphragm, intercostal, and abdominal muscles. The motor outputs for controlling respiration are generated by efferent neurons in the spinal cord. There are autonomic and voluntary breathing pathways to these respiratory-related efferent neurons. A variety of afferent (sensory) inputs influence respiratory rate and tidal volume in support of the body's metabolic demands. SNS activity increases respiratory rate and PsNS activity reduces respiratory rate.

4. **Electroencephalogram (EEG)** - Several EEG studies suggest that valence is linked to frontal lobe activation. Positive valence is correlated to increased activation of the right frontal lobe and negative valence is correlated to increased activation of the left frontal lobe.

5. **Electrodermal Activity (EDA)** - EDA is a physiological signal that indicates increased SNS activity. EDA is representative of changes in the electrical conductance of the skin due to eccrine (sweat) gland activity. SNS activity increases sweat gland secretions. Eccrine glands only receive activation signals from the SNS, so increased EDA is an indicator of increased arousal.

6. **Electromyogram (EMG)** - Zygomaticus (smiling) and corrugator (frowning) muscles are SoNS innervated, however facial expressions typically manifest suddenly, without extensive conscious intervention. In practice, the activation of zygomaticus and corrugator have been demonstrated to be indicative of emotional valence.

This application note is concerned with the implementation details of determining emotional state based on three physiological measures. Higher arousal can be identified by increasing EDA. Zygomaticus EMG activity is representative of positive valence (pleasure); negative valence (displeasure) is indicated by corrugator EMG activity.
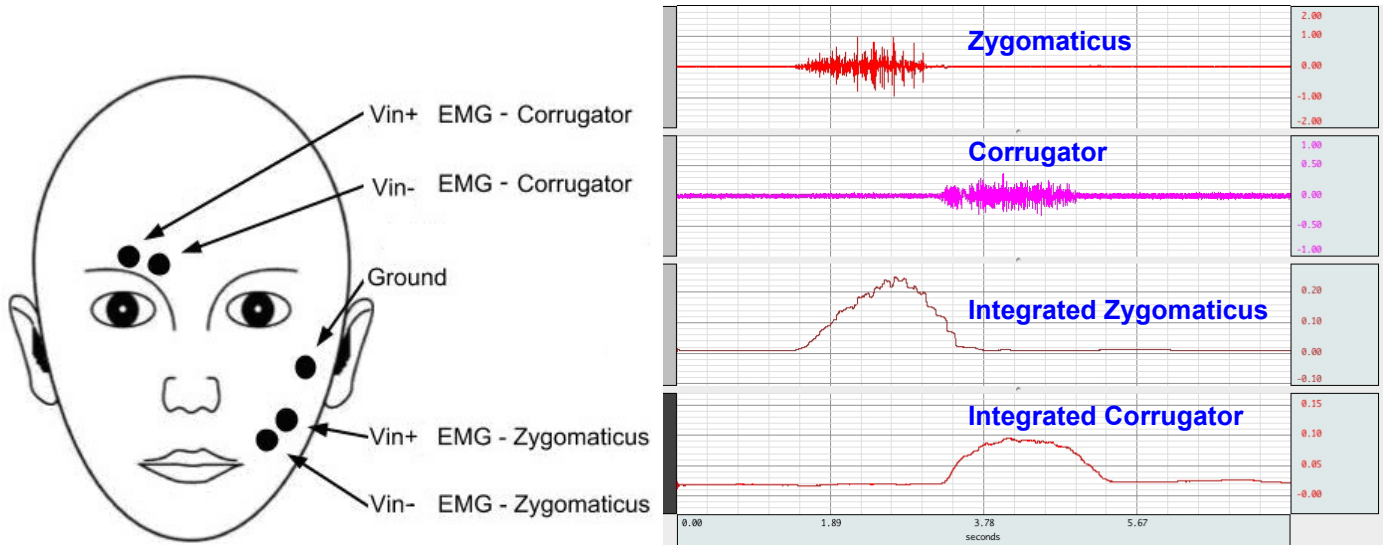
EMG Electrode Placement & Facial and Integrated EMG recorded to MP System

Integrator Setup in Acq*Knowledge* Software

Use Sample rate 2,000 Hz and add a Calculation channel for 1500 point moving root mean square (RMS) calculation.
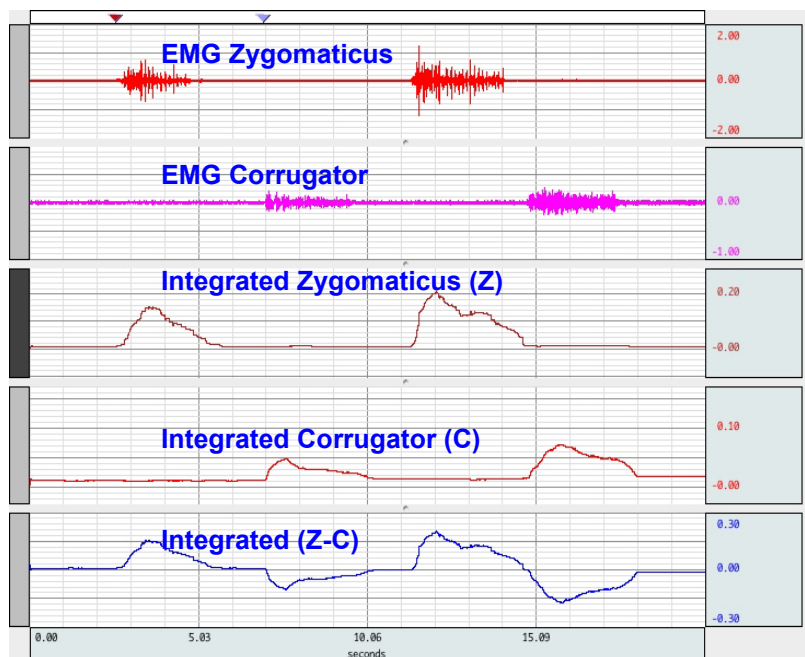
Facial, Integrated, and Normalized EMG recorded to MP System

The Expression calculation channel in Acq*Knowledge* is set to Integrate. EMG Z and EMG C values are offset adjusted and then scaled to provide normalized valences for pleasant and unpleasant affect.
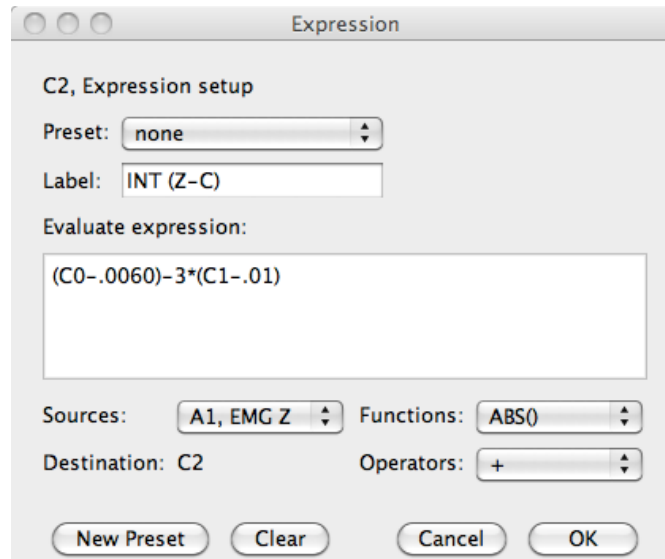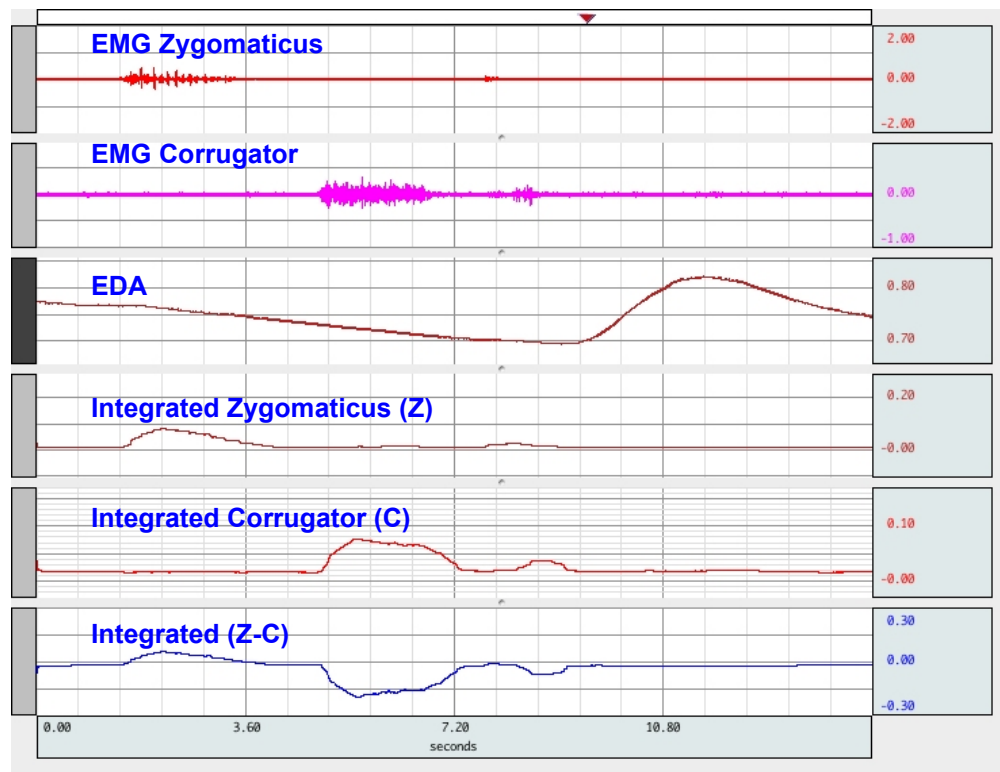

Integrated (Z-C) Expression Setup in Acq*Knowledge*

EDA Setup

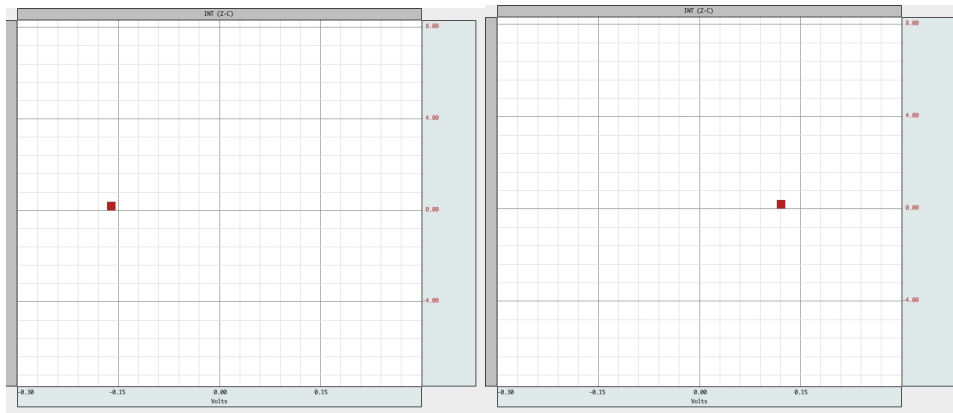EDA attachment to MP System – transducer TSD203 shown; disposable electrode options available

EDA and Facial, Integrated and Normalized EMG recorded to MP System

Note location of square dot in each frame
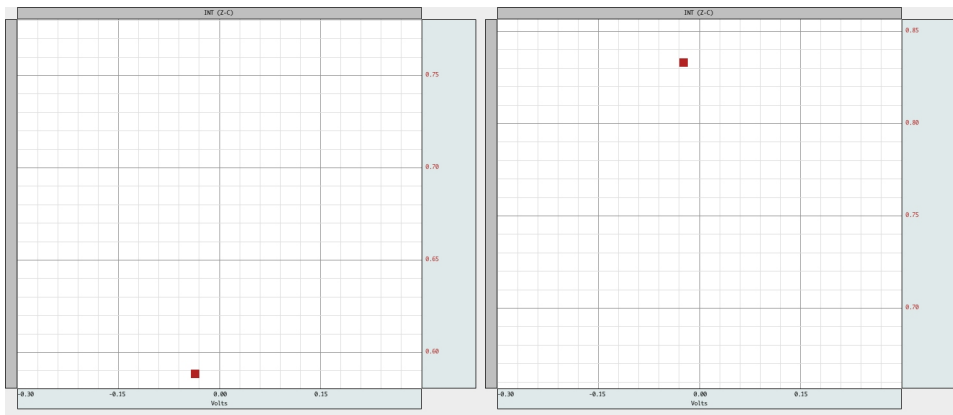
- Use X/Y Plotting Option (last dot only) for Real-time Emotional State Estimate:

X-Axis: Integrated (Z-C); Y-Axis: EDA.

Valence - Unpleasant   Valence - Pleasant
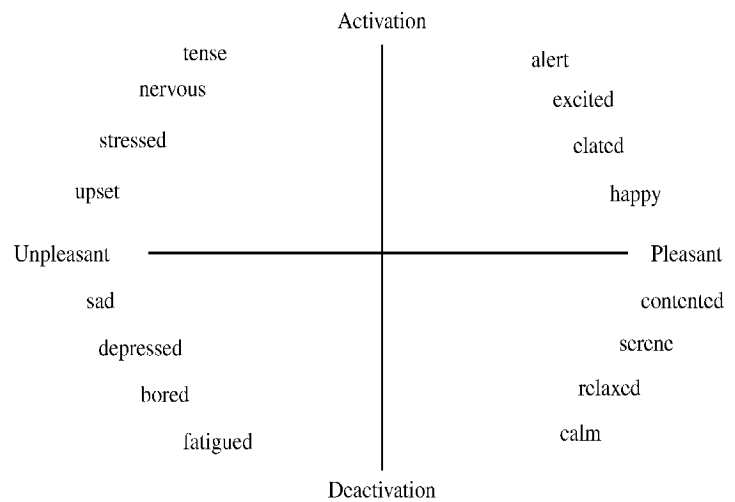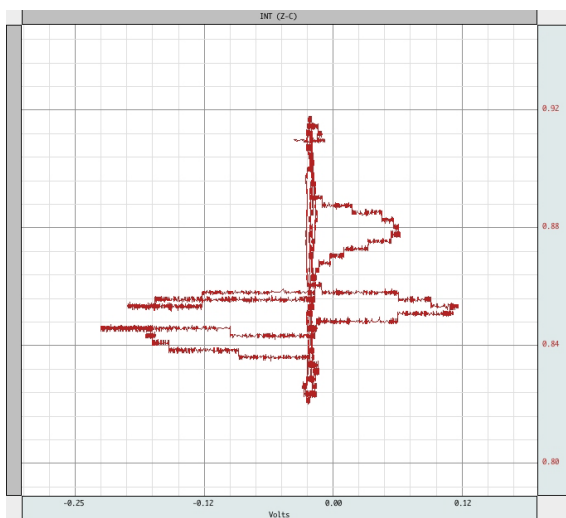

Arousal - Deactivated   Arousal - Activated

- Use X/Y Plotting Option (plot all) for Real-time Emotional State Estimate vs. Time. X/Y plot shows path of emotional state history**.**

X-Axis: Integrated (Z-C); Y-Axis: EDA

Source: Feldman-Barrett and Russell (1998)