INTRODUCTION

Human natural affective behaviour is multimodal, subtle and complex. In day-to-day interactions, people naturally communicate multimodally by means of language, vocal intonation, facial expression, hand gesture, head movement, body movement and posture, and possess a refined mechanism for understanding and interpreting information conveyed by these behavioural cues.

Despite the available range of cues and modalities in human-human interaction (HHI), the mainstream research on human emotion has
mostly focused on facial and vocal expressions and their recognition in terms of seven discrete, basic emotion categories (neutral, happiness, sadness, surprise, fear, anger and disgust; Keltner & Ekman, 2000; Juslin & Scherer, 2005). In line with the aforementioned, most of the past research on automatic affect sensing and recognition has focused on recognition of facial and vocal expressions in terms of basic emotional states, and then based on data that has been posed on demand or acquired in laboratory settings (Pantic & Rothkrantz, 2003; Gunes, Piccardi, & Pantic, 2008; Zeng, Pantic, Roisman, & Huang, 2009). Additionally, each modality—visual, auditory, and tactile—has been considered in isolation. However, a number of researchers have shown that in everyday interactions people exhibit non-basic, subtle and rather complex mental/affective states like thinking, embarrassment or depression (Baron-Cohen & Tead, 2003). Such subtle and complex affective states can be expressed via tens (or possibly hundreds) of anatomically possible facial expressions, bodily gestures or physiological signals. Accordingly, a single label (or any small number of discrete classes) may not reflect the complexity of the affective state conveyed by such rich sources of information (Russell, 1980). Hence, a number of researchers advocate the use of dimensional description of human affect, where an affective state is characterized in terms of a small number of latent dimensions (e.g., Russell, 1980; Scherer, 2000; Scherer, Schorr, & Johnstone, 2001).

It is not surprising, therefore, that automatic affect sensing and recognition researchers have recently started exploring how to model, analyse and interpret the subtlety, complexity and continuity of affective behaviour in terms of latent dimensions, rather than in terms of a small number of discrete emotion categories.

A number of recent survey papers exist on automatic affect sensing and recognition (e.g., Gunes & Piccardi, 2008; Gunes et al., 2008; Zeng et al., 2009). However, none of those focus on dimensional affect analysis. This paper, therefore, sets out to explore recent advances in human affect modelling, sensing, and automatic recognition from visual (i.e., facial and bodily expression), audio, tactile (i.e., heart rate, skin conductivity, thermal signals etc.) and brain-wave (i.e., brain and scalp signals) modalities by providing an overview of theories of emotion (in particular the dimensional theories), expression and perception of emotions, data acquisition and annotation, and the current state-of-the-art in automatic sensing and recognition of emotional displays using a dimensional (rather than categorical) approach.

BACKGROUND RESEARCH

Emotions are researched in various scientific disciplines such as neuroscience, psychology, and linguistics. Development of automated affective multimodal systems depends significantly on the progress in the aforementioned sciences. Accordingly, we start our analysis by exploring the background in emotion theory, and human perception and recognition.

THEORIES OF EMOTION

According to the research in psychology, three major approaches to emotion modelling can be distinguished (Grandjean, Sander, & Scherer, 2008): (1) categorical approach, (2) dimensional approach, and (3) appraisal-based approach.

The categorical approach is based on research on basic emotions, pioneered by Darwin (1998), interpreted by Tomkins (1962, 1963) and supported by findings of Ekman & his colleagues (1992, 1999). According to this approach there exist a small number of emotions that are basic, hard-wired in our brain, and recognized universally (e.g., Ekman & Friesen, 2003). Ekman and his colleagues conducted various experiments on human judgment of still photographs of deliberately
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