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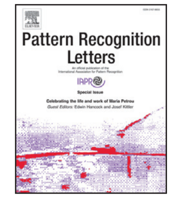

Recognizing affect in human touch of a robot ☆

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ABSTRACT

A pet cat or dog's ability to respond to our emotional state opens an interaction channel with high visceral impact, which social robots may also be able to access. Touch is a key but understudied element; here, we explore its emotional content in the context of a furry robot pet. We asked participants to imagine feeling nine emotions located in a 2-D arousal-valence affect space, then to express them by touching a lap-sized robot prototype equipped with pressure sensors and accelerometer. We found overall correct classification (Random Forests) within the 2-D grid of 36% (all participants combined) and 48% (average of participants classified individually); chance 11%. Rates rose to 56% in the high arousal zone. To better understand classifier performance, we defined and analyzed new metrics that better indicate closeness of the gestural expressions. We also present a method to combine direct affect recognition with affect inferred from gesture recognition. This analysis provides a unique first insight into the nature and quality of affective touch, with implications as a design tool and for incorporating unintrusive affect sensing into deployed interactions.

1. Introduction

An interactive affective computing system requires automatic, realtime recognition of affect. In the past decade, extensive research in affect recognition has focused on vision, speech, physiological measurements, and their fusion [3,5,27]. However, the touch modality has not been widely considered, despite evidence that it is a potent means for emotion communication [11,12,14].

Recognition of different aspects of affect via touch will enable a substantially different approach to interactive applications, because of its potential for unintrusive use. Meanwhile, situated in an object rather than a space (as for vision), it can be built around interactions rather than a viewpoint from a fixed space. Touch-based affect sensing comprises a pipeline whose elements each impact ultimate recognition performance:

- the user's actual emotional state, its typical manifestation, and degree to which this is expressed in his/her touch;
- the object being touched, and the social and physical context of the interaction, both of which impact the expressiveness of the touch that is invited;
- data quality, namely the sensors used and their ability to detect expressively informative touches;
- recognition algorithm, delivering probabilities of a particular affective user state;
- metrics used to incorporate *a priori* known risk of misclassification.

Recently, good results have been obtained in touch-based affect recognition [20], which captures one interesting path through this large design space (Section 1.1).

In the present work, we explore the premise of human interactions with a haptically inviting and expressive social robot. In this context, interpretation of affective touch originating from the human, usually from a combination of endogenous origins and response to robot behavior, can potentially support closed-loop responsiveness in social human-robot interaction (HRI) settings, for example for therapeutic, caregiving and companionship applications with pet and humanoid robots. Our studies employ the Haptic Creature (Fig. 1), a robot pet that mimics a small animal sitting on a person's lap.

Approach: Our research, based on a robot pet platform that displays as well as senses touch stimuli, utilizes a dimensional representation of affect. The resulting structure should be helpful in robot sensing of human affect, by mitigating the impact of 'noisy' classification through a concept of 'near misses' and of natural, i.e. higher-likelihood transitional paths; and in robot rendering of its own affect display, via a topological map of coherent dynamic transitions. In a previous study, participants performed a series of specified touch gestures on the robot as they imagined feeling different emotions, and touch data were recorded using first-generation touch sensors. An analysis of the visual and video observation of these gestures has been published [26]. However, these methods come at a high cost of labor,

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Fig. 1. The Haptic Creature, in experiment context.

processing delay and the intrusiveness and privacy issues of video recording.

Here, we use pattern recognition on this study's unpublished touch sensor data to assess feasibility and best methods for classifying the gesture-giver's affective state, and to generate requirements for next-generation touch sensing. We consider two schemes: (1) recognizing affect directly from touch data, and (2) identifying touch gestures *and* inferring affect information from gesture, then combining these two information sources.

1.1. Related work

1.1.1. Affective content in touch gestures

The first item in our pipeline indicates the central assumption that the user's touch is emotionally informative. Evidence that it can be comes from multiple sources. Touch has long been observed in real situations by social scientists to encode social meaning, albeit modified by factors such as relationship, hierarchy and context [13]; and studies in nursing chronicle its use for healing, *e.g.*, [1]. In controlled environments, individuals asked to imagine feeling varying emotions are observed to make different touch gestures [26], and those asked to *express* different emotions to a human or mannequin arm make gestures and touch patterns that can be distinguished and which correlate to the instructed emotion [20].

It remains to validate identifiable information content in touches made under authentic emotional circumstances. This effort will be assisted in future by a system able to capture touch data automatically along with other verifying context (e.g. voice prosody, caregivers' reports). The present work is a step toward that end.

1.1.2. Affective classification of touch gestures

Affect representations in use today generally take one of two forms. A *categorical* approach models affective states as independent classes; a *dimensional* approach organizes them with a systematic relation [10]. Of the latter, the most well-known is Russell's circumplex model of affect [15], which locates emotions on dimensions of valence (x-axis) and arousal (y-axis). Following the experiment design under which our data were collected, fully motivated in [25], we use a modification of the circumplex model known as the *affect grid* ([16],

e_1 distressed	e_2 aroused	e_3 excited
e_4 miserable	e_5 neutral	e_6 pleased
e_7 depressed	e_8 sleepy	e_9 relaxed

Fig. 2. Emotion labels (from [16]) and their locations in the affect grid, as adapted by Yohanan and MacLean [26].

Fig. 2). Further discussion and review of continuous emotion models can be found in [10], and in [9] in the context of affect recognition, and we refer the reader to Silvera-Tawil et al. [20] for a comprehensive review on tactile HRI.

Past efforts have typically employed two steps to recognize affect out of touch, first identifying the gestures and then attaching an affective meaning to those gestures. For example, the robot seal PARO [19] can sense if it is being stroked *vs.* hit through its touch sensors. Huggable's more sophisticated algorithm and structure distinguishes nine touch gestures [21]. Probo defines three gestures at a higher level—a hug, scratch, or hurt [17]; AIBO detects only touch location of touch [8]. All these robots employ some kind of gesture recognition as part of affective communication.

Most relevantly and recently, Silvera-Tawil et al. [20] asked subjects to display specified emotion messages to a real human arm, and to a mechanical proxy with touch sensors. Six emotion states were recognized with accuracy comparable to humans (47%–52%) representing to our knowledge a first instance of machine recognition of affective content in touch.

Our study, while sharing a general aim, differs throughout the recognition "pipeline". We employed a human-pet paradigm: touching a nice-feeling animal proxy is socially very different from touching a human or its proxy. Rather than *communicate* a specific emotion, our subjects were instructed to *imagine* different emotional states, and to interact as if with a real pet companion; it is unclear at this stage whether this makes the classification problem harder (display is not explicit) or easier (more natural circumstance makes differences more clear). Sensing was accomplished with discrete transducers rather than a continuous sensed sheet, producing discontinuous data which likely impacted ultimate performance. Finally, we implemented metrics based on a dimensional representation of emotion, allowing us to apply distances to the topological connections between actual and detected affective states. To our knowledge, recognizing and classifying affective touch in such a setting is new.

1.2. Research questions and contributions

This study aims to answer, in the context described above:

- How far can we push the limits of inexpensive sensors by applying advanced machine learning methods to extract affect information from touch?
- Is a dimensional (*e.g.*, 2-D arousal/valence space) representation informative for affective touch?
- What are good performance metrics for dimensional affect recognition?
- Which emotion states of those examined here tend to be confused by our algorithm and sensor?
- Is inferring affect directly from gestures more or less effective than recognizing gestures then attaching emotional meaning to them, for the conditions studied here?

Our original contributions are the following:

- Insights into the feasibility of classifying affect directly from touch data, in the realistic case where the touch-giver is not explicitly trying to communicate it.

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