Non-anthropomorphic expression of affective states through parametrized abstract motifs

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Abstract—One of the key challenges of affective computing is to extend the expression of emotions to machines. Research in this field has focused mainly on embodied machines that can reproduce verbal or non-verbal cues such as facial movements and gestures. However, most machines we interact with in our daily life are non-anthropomorphic. For this reason, the question we are addressing in our study is whether it is possible to express emotions or affective states using non-anthropomorphic cues in non-humanoid artifacts.

We generated animated motifs using a small set of parameters (color, motion and complexity) and we displayed them on the interactive floor of the eXperience Induction Machine (XIM), an immersive mixed reality space. We asked the participants to assess the emotions attributed to these abstract visual cues. Our findings suggest that it is not only possible to express affective states, but also to modulate human behavior through non-anthropomorphic and abstract stimuli.

Keywords—Affective computing; Color; Emotion recognition; Human computer interaction; Virtual Reality;

I. INTRODUCTION

One of the key challenges of affective computing is to extend the expression of emotion to machines [1], [2]. To recognize emotions, humans spontaneously rely on visual [3], [4], auditory [5], and olfactory [6], [7] cues. For this reason past research mainly focuses on embodied machines which can simulate anthropomorphic expressions such as facial movements and gestures [8], [9], [10].

It is known, however, that our brain responds to non-anthropomorphic emotional signals [11], [12], [13]. Yet, there is still sparse evidence about the affective components of abstract cues. It is consequently worthwhile to investigate the affective potential of such artifacts.

A few studies in the field of affective computing have addressed the topic of emotion expression using disembodied environmental cues such as lighting, shadows [14], [15], [16] and colors [17]. These researches, however, still present an anthropomorphic component since the environmental cues used to manipulate the expression of emotions were applied to virtual humans or avatars. In the current study we aim to exclude these anthropomorphic components and to focus on the mechanisms that underlie the expression of affect in non-anthropomorphic stimuli applied to non-humanoid artifacts.

For this reason, we conducted an experiment using the interactive floor of the mixed reality space eXperience Induction Machine (XIM), an immersive room equipped with a number of sensors and effectors that has been constructed to conduct experiments in mixed reality [18].

The floor of the XIM had been originally custom-built for the interactive space called “Ada”. Ada was intended to behave as a creature with distinct behavioral states. It was developed for the Swiss national exhibition Expo.02 and had over half a million visitors. The space communicated its internal states to the visitors through an interactive sound-light-graphics composition that evolved over time. These internal states, or emotions, were derived from the ability of the space to achieve its behavioral goals [19].

With Ada we have shown that changes in the environmental settings affected the users’ attitudes and behavior [20]. Here we aim to develop Ada’s paradigm and to conduct a more systematic empirical validation.

We generated animated visual motifs using a small set of parameters (color, motion and complexity) intended to express a wide range of possible emotional cues and we displayed them on the interactive floor of the XIM.

In the context of our experiment, the use of XIM offered several advantages when compared to a standard experimental setting (e.g. a computer screen). In the XIM the subjects experience an enhanced level of immersion (they literally walk on the stimuli presented). At the same time behavioral cues, such as the subjects’ movements in the space, can be recorded.

For the empirical evaluation we assessed which emotion the participants attributed to the motifs they were exposed to. In addition, we analyzed the tracking data collected from the subjects’ position in the space.
Motif 1 (M1) Motif 2 (M2) Motif 3 (M3)

Figure 1. Illustration of the 3 motifs. Motif 1 (left, warm scheme) explores both horizontal and vertical movements. It is composed of two layers: the higher one consists of a vertical line which loops from right to left and vice-versa. The second layer represents vertical lines which move horizontally from both sides of the floor. Motif 2 (center, cool scheme) represents a monochromatic circle that starts from the center and expands centrifugally. This animation is composed of 1 higher layer (circle) and a colored background layer. Motif 3 (right, complementary scheme) consists of monochromatic diagonal lines. It is composed of 1 higher layer and a colored background layer. The arrows indicate the entrance of the XIM.

II. METHODS

A. Parametrized motifs

Our goal was to generate abstract visual motifs based upon a small set of parameters intended to express a wide range of possible emotional cues. One of the main challenges of our study was to reduce the option space for the motifs to display on the floor of the XIM to as few dimensions as possible.

1) Color: Previous research has shown that colors act as emotion elicitors in humans and that in the color domain there are strong universal trends in the attribution of affect [21]. For this reason we chose to explore the impact of chromatic stimuli on the non-anthropomorphic communication of affect. A hue-based classification was applied. Three chromatic schemes were adopted to elicit different emotional states according to the literature on colors: “warm” (long-wavelength hues), “cool” (short-wavelength hues) and “complementary”. Short-wavelength hues (e.g. blue, green) are pleasant and soothing, while long-wavelength hues (e.g. yellow, orange) are perceived as negative and physically arousing [22], [23], [24]. The complementary scheme consists in pairs of colors with different hues that in some circular color models (such as the traditional Goethe’s color wheel [25]) have a diametrically opposite hue (e.g. red/green, blue/orange, yellow/violet). They are widely employed in art and design due to their high contrast and pleasantness. In scientific literature complementary colors are associated to balance or harmony [26]. However, to the best of our knowledge, no previous studies directly addressed their affective properties. For this reason they are worthwhile to investigate.

2) Motion: Visual motion of a stimulus affects internal states, in particular arousal [27], [28]. For this reason we chose to generate animated motifs composed of 2 or more frames that we categorized according to 2 values of motion: slow motion (1fps) and fast motion (~10fps) representative respectively of the minimum and the maximum refresh rate the neon tubes in the XIM floor can reach. Due to the slow refresh frequency of the floor, values in–between the maximum and the minimum frame rate were discarded because not easily detectable.

3) Complexity: To evaluate empirically and compare different abstract motifs required a quantitative measure that we defined as complexity.

Previous research showed that the complexity of visual patterns affects pleasantness, interest and arousal, [29], [30]. Studies in the fields of psychophysics and perception indicated that several factors (e.g. symmetry, repetitions) appear to be related to the complexity of a visual pattern [31]. These factors, however, may vary in accordance to the intrinsic properties of the stimulus (e.g. randomly or geometrically distributed spatial frequency).

Each animated motif comprised a number of colors (in accordance to the chromatic schemes we adopted), a number of frames that composed the animation and one or more layers for each frame. The layer mechanism facilitated the creation of complex animated motifs (e.g. by allowing the use of a fixed background color for all the frames).

We quantified the visual complexity of our animated motifs as a linear combination of number of frames, number of colors used and number of layers composing the motif.

4) Selection of the stimuli: Based on the complexity parameter space, 50 distinct animated motifs were created. 5 jurors were asked to rate the complexity of each one of the generated stimuli on a scale from 1 to 9. Based on the ratings collected, we identified 3 categories: low (rating 1 to 3), medium (rating 4 to 6) and high (rating 7 to 9). For each category we chose the motif that received the highest number of ratings, thus obtaining 3 motifs (M1, M2, M3), each of which was representing a different degree of complexity (Fig. 1).

Each one of the 3 motifs could be reproduced on the XIM floor according to the 3 color schemes and the 2 values of motion, resulting in a total of 18 combinations.

Next to this, we added 1 non-animated control motif.
(M4) composed of a single neutral color (white). Hence we obtained a total of 19 combinations classified according to the parameters of color, motion, and complexity.

B. The eXperience Induction Machine

The eXperience Induction Machine (XIM) is an immersive multi-user mixed reality space (5.5m x 5.5m, 4m high) equipped with a number of sensors and effectors (Fig. 2).

The key component for this study is the luminous floor composed of 72 hexagonal tiles. Each tile is serially chained to its neighbour and comprises an aluminum frame, a glass top, a microcontroller, analog load sensors and dimmable RGB neon lamps. The maximum tile luminance of 200 cd/m² is comparable to the emission of a standard computer display [32].

C. Motifs animation framework

To display animated motifs on the floor of XIM in real time required the development of a new software framework. For this purpose the “XIM floor animation framework” was developed. This framework allows to draw motifs on the XIM floor, create the frames, the layers and control the animations ( framerate from 0.5fps to 10fps, loop, pause and resume). The information about the animated motifs were stored in XML files.

The state of the active floor tiles is specified by a set of frames, assigning an RGB color value to each tile. The framework replaces the inactive tiles with a null value or a monochromatic color if a background layer is chosen. The engine supports up to two layers, which are automatically blended before the value array is sent to the floor. To simulate the floor behavior during the drawing and testing process, a drawing tool and a live preview of the animated motifs were developed.

D. Empirical evaluation

The aim of the empirical evaluation was to assess the emotional connotation of each motif combination.

Our hypothesis is that it is possible to express affective states using abstract parameters (color, motion and complexity) in a non-humanoid artifact such as the XIM.

The assessment was done through questionnaires based on the self-assessment manikin (SAM) [34], which measures 3 affective dimensions: pleasure, arousal and dominance on a scale from 1 to 9. Additionally, one open-ended question which asked how the participant would describe what the floor was expressing was administered.

25 healthy adults (15 females, mean age 24.6, SD±4.2) from 10 countries (48% Spain) were recruited among the undergraduate students of the Universitat Pompeu Fabra in Barcelona.

E. Experimental protocol and data collection

The experimental protocol comprised single participant sessions in XIM. During one session a participant was exposed to 6 randomly selected motifs out of the pool of 19 combinations.

Prior to the exposure, the participants were instructed to enter the XIM and place themselves at the designated starting point. Each motif was displayed as a looping animation with a duration of 1 minute. After each motif, the subject filled in the questionnaire, resulting in 6 questionnaires per participant.

Additionally the spatial location of the participant during the experiment was recorded for each experimental session through the XIM tracking system [35].

In total, each one of the 19 parametrized motif combinations was tested 8 times on average (i.e. 17 combinations were tested 8 times, while 2 combinations were tested 7 times).

III. RESULTS

A. Questionnaires data

We conducted a Kruskal-Wallis test to evaluate differences among the dimensions measured through the SAM questionnaire (pleasure, arousal and dominance) and the color parameter. We obtained a significant effect between color and pleasure ($\chi^2 = 18.6, p < .001$) and between color and arousal ($\chi^2 = 15.2, p = .002$).

Mann-Whitney tests were used to follow up these findings. A Bonferroni correction was applied to control for Type I error across tests. The results of these tests indicated a significant difference in pleasure between the warm and the cool scheme ($p < .001$) and between the warm and the complementary scheme ($p = .001$). Furthermore the tests indicated a significant difference in arousal between the cool and the warm schemes ($p = .009$), between the cool and the complementary schemes ($p = .003$), and between the neutral and the complementary schemes ($p = .008$).

The warm scheme obtained significantly lower ratings in pleasure ($M = 4.81, SD = 2.319$) than the complementary ($M = 6.60, SD = 1.996$) and the cool ($M = 6.65, SD = 1.792$) schemes (Fig. 3).

The cool scheme obtained significantly lower ratings in arousal ($M = 5.10, SD = 2.146$) than the warm ($M = 6.28$, SD = 1.89).
Figure 3. Boxplots showing significant differences in pleasure ratings. The warm scheme obtained significantly lower ratings than the cool and the complementary schemes.

Figure 4. Boxplots showing significant differences in arousal ratings. The cool scheme obtained significantly lower ratings than the warm and the complementary schemes. The neutral scheme obtained significantly lower rating than the complementary scheme.

SD = 2.154) and the complementary (M = 6.49, SD = 1.816) schemes. The neutral scheme obtained significantly lower ratings in arousal (M = 3.75, SD = 2.765) than the warm scheme (Fig. 4).

Finally, we found a positive correlation between arousal and motion (p = .409, p < .001).

No statistical significance was found between the parameter of complexity and the dimensions measured through the SAM questionnaire.

B. Open-ended questions data

Next to the SAM scales, each questionnaire included one open-ended question asking the participant for a description of what was expressed on the floor.

Participants frequently replied to the open-ended question using a finite set of words and associations (e.g. stress, quiet, obsession).

To perform a quantitative analysis we operated a classification of the answers to the open-ended questions [36], [37]. We devised three semantic categories that we named as “swiftness”, “positivity” and “evocation”. The participants’ answers were categorized semantically and assigned a value of either 0 or 1 for each one of the three categories as shown in Table I.

Some statements, however, were not semantically classifiable and were labeled as Omitted and excluded from the statistical analysis.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>swiftness</td>
<td>Expressing either a sensation of quiet or stress</td>
<td>Value 1 = semantic sphere: quiet, calm, slow, relaxing, peaceful, etc... Value 0 = semantic sphere: stress, dynamic, alert, excitation, frenetic, tension, chaos, etc...</td>
</tr>
<tr>
<td>positivity</td>
<td>Expressing either a positive or negative sensation</td>
<td>Value 1 = semantic sphere: happiness, positive, comfortable, etc... Value 0 = semantic sphere: sad, disturbing, suffocating, uncomfortable, etc...</td>
</tr>
<tr>
<td>evocation</td>
<td>The motif is associated to ideas or memories</td>
<td>Value 1 = the open answer contains locutions such as: as if, seemed like, looked like, it reminds me, etc... and can be considered as a metaphor (e.g. the Catalan flag, the ocean, etc...). Value 0 = no association to ideas or memories. No metaphors.</td>
</tr>
</tbody>
</table>

We correlated the ratings measured through the SAM questionnaire (pleasure, arousal and dominance) with the values attributed to the open answers for each category (swiftness, positivity and evocation). We found a significant positive correlation between positivity and pleasure (ρ = .277, p < .01) and between evocation and pleasure (ρ = .147, p < .05). Additionally we found a significant negative correlation between positivity and arousal (ρ = -.137, p < .05).

No significant correlations were found between the dimensions measured through the SAM questionnaire and the category of swiftness.

C. Behavioral data

The spatial coordinates of the participant were recorded during each experimental session.

First, we calculated the mean velocity of the participants for each trial. The data satisfied the normality criterion as
verified using the Lilliefors test, and was analyzed with a three way ANOVA, with factors 3 motifs (motif 4 was excluded as not animated) x 2 motion values x 3 color schemes. The analysis showed that the motif factor had a significant effect on the mean velocity ($F(2, 120) = 4.3$, $p < .02$). The post-hoc Bonferroni test for the velocity showed a significant difference between motif 1 and motif 3 ($p < .05$) (Fig. 5).

Second, we quantified the spatial distribution of the participants by the time spent in different regions of XIM. We divided the XIM in three equal regions – front, center and back area – on the x-axis. The front area was defined as one third of the space divided on the x-axis.

The non-parametric data was submitted to a Wilcoxon-Rank-Sum Analysis, testing differences on the median.

We applied error correction and found significant differences in occupation time of the front area between motif 1 and motif 3 ($p = .001$) and between motif 2 and motif 3 ($p = .002$). Participants spent significantly more time within the frontal area when exposed to motif 3 (Fig. 6).

IV. CONCLUSION

The goal of our study is to find how affective states (pleasure, arousal and dominance) can be expressed using abstract, highly parametrized visual cues in non-humanoid artifacts. The motivation of this research originated from the “Ada” experience [19] and is of relevance to our understanding of how machines can communicate their internal states exclusively through non-anthropomorphic means.

We conducted an experiment in an ecologically valid mixed reality space called eXperience Induction Machine (XIM). We generated animated motifs that were displayed on the interactive floor of the XIM. These motifs were parametrized according to 3 dimensions: color, motion and complexity.

We evaluated the participants’ explicit and implicit responses analyzing respectively their answers to the questionnaire and their spatial behavior.

A number of relationships between the parametrized motifs and the recognition of affective states assessed by the participants was found.

The analysis of the data collected through the questionnaires revealed a significant relationship between the color schemes adopted and the dimensions of pleasure and arousal measured through the SAM scales.

The warm scheme obtained significantly lower ratings in pleasure than the complementary and the cool schemes. The cool scheme obtained significantly lower ratings in arousal than the warm and the complementary schemes. The neutral scheme didn’t have any effect in pleasure while obtained significantly lower ratings of arousal than the complementary scheme. Additionally, the complementary scheme obtained significantly high ratings of arousal and pleasure.

These findings are not only consistent with the previous literature on colors and emotions (Section II-A1), but show that the expression of affective states through colors does not necessarily rely upon the medium used to display the stimuli. We were able, in fact, to replicate on the luminous floor of the XIM the results obtained in previous studies using booklets and computer screens. In addition, while previous research mainly adopted single-color stimuli, we operated a hue-based categorization of colors into different color schemes (short and long wavelength and complementary) thus showing that the results of previous studies that adopted monochromatic color stimuli can be extended to polychromatic stimuli when the colors composing each stimulus have common intrinsic features such as relationships between the
hue values.

We performed a quantitative analysis of the answers to the open ended questions by classifying them into 3 semantic categories (swiftness, positivity and evocation). We found a positive correlation between positivity and pleasure and between evocation and pleasure. We also found a negative correlation between positivity and arousal. These results indicate that the verbal assessment of the participants (i.e. their answers to the open-ended question) was consistent with their non verbal assessment (SAM ratings).

Furthermore, we found a positive correlation between the motion parameter and the arousal. Motifs played at a fast frame rate obtained higher ratings in arousal. This correlation is consistent with previous research (Section II-A2).

While the parameter of complexity didn’t obtain significant results in the expression of affective states assessed by the participants, it played a significant role in the modulation of their behavior. Indeed, the analysis of the spatial data collected through the XIM tracking system showed a significant relationship between the complexity of the motifs (M1, M2 and M3) and the participants’ behaviour in the space. In particular, we found a significant increase in the participants’ velocity and in the time they spent in the frontal region of the XIM when exposed to Motif 3 (which moves along a diagonal path, as shown in Fig. 1). The reasons underlying these results are not clear and further investigation is required. A more systematic determination of the complexity parameter (e.g. a classification based on geometric features such as symmetry and distribution) will offer new insights on the obtained results.

Taken together, our findings suggest that it is not only possible to express affective states (pleasure and arousal), but also to modulate human behavior through non-anthropomorphic and abstract parameters.

The environment where we live is becoming more and more a media platform and most machines we interact with today are non-humanoid. There is, therefore, a definite need for new means of human-environment and human-machine communication. Our study represents a step further in this direction.

Future improvements of our research include the introduction of physiological measures (such as electrodermal response and heart rate) to validate the parameters of colors and motion not only in the recognition, but also in the induction of affective states.

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REFERENCES


