A Development of an Emotion-Responsive Color Adaptation for Interactive VR Model

Ju Yeon Kim*1 and Hyun Soo Lee2

1 Ph.D Candidate, Department of Housing & Interior Design, Yonsei University, Korea
2 Professor, Department of Housing & Interior Design, Yonsei University, Korea

Abstract
One of the main motivations of this research is to develop an adaptable Virtual Reality (VR) model whose color can be changed dynamically according to the identified emotional state of a user. This paper addresses how to capture a specific user’s emotion through the web and use it for modifying VR model mainly for color adaptation. This adaptation process of a VR model consists of three phases: 1) identification of the user’s emotional state projected onto the selected paintings, 2) translation of those captured emotional keywords into a pertinent set of color coordinations, and finally, 3) automated color adaptation process for the given VR model. In this paper, we introduced a method of using well-known paintings and their variations to derive an on-line viewer’s emotional state which can be utilized to find a new color scheme reflecting the identified emotion. This color harmony scheme can provide a useful information for a dynamic color coordination for the objects embedded in the given VR model. The outcome of this study could enable an interactive and dynamic VR model supporting emotion-responsive interior design simulations or the visionary scenario of the architectural environment where interior colors are changed according to the captured mood of the occupant.

Keywords: emotion-responsive, color, VR model

Introduction
Up to now, the concept of Virtual Reality (VR) has influenced diversified industries all over the world. A set of visual elements is undoubtedly the major medium for constructing VR model while the Human-Computer Interaction (HCI) is becoming more and more graphically orientated. The evolution of virtual space or VR has led to an innovative human-computer interaction medium with a potential to present the ‘ideal’ interface between users and a computer generated synthetic environment. VR offers an almost unlimited space and it can represent and provide interactions in real-time (Kalawsky, 1998). The majority of virtual interfaces are designed to represent existing physical spaces or structures. However, VR systems are also very powerful for visualizing and interacting with large or abstract multi-dimensional environments (Kalawsky, 1993).

In the mean time, many tasks in architectural practice are becoming digital through the use of computers, especially in design process. Interestingly enough, various objects in digital world are also becoming architectural through the increasing use of 3-D simulated environments to comprehend and navigate digitized information space. In response to the growing demand, researchers set out to build interactive Virtual Space capable of being updated according to the user specific information. Virtual Space, seen not only as technology but also as experience, brings 3D object which traditionally have been described and represented in an abstract way. One of the most important criteria of an interactive interface is to give the user a chance to have a vivid experience with it. It is obvious that the user oriented design and even the pursuit of emotion-associated satisfaction are getting more attention on the web-based systems.

The importance of communicating affective information is often ignored in interaction design. Designers have built systems that try to help a user, but they have not built systems that see if offers of help irritate or please the user. In our minds, this lack of attention to the user’s response is disrespectful and sort-sighted. A smart environment is necessary for this reason. The smart environment is one that is able to identify people, interpret their actions, and react appropriately. Thus, one of the most important building blocks of a smart environment is a person identification system. As Japan Sensibility Marketing Research (Kunio Sato, Tesuya Hirasawa, 1996) suggested, emotional product industry is progressing and considered to be important. An emotion-responsive interface is indispensable even in the cyber space for enhanced immersion and satisfaction.
Why Adaptive VR Model?

If a computer can recognize human emotional state and react accordingly, we might think it has a certain level of intelligence. But in reality, this still is a part of science fiction. It is clear that not a single human can completely recognize their own deep emotion, actually in many instances, people cannot even recognize their own emotions. Internal feelings could remain private as long as we want them to be that way or if we sufficiently conceal them from being known to others. In this case, the external recognizers can only observe or reason about the feelings of others, which always are subject to some uncertainty. Despite this uncertainty, people want to know about each other’s emotion to communicate useful feedback. The partial goal of this research is to give computers cognitive capabilities similar to those that people have so that they can respond to a set of perceptual stimuli.

The process in which the colors of an interior space are dynamically changed according to a characteristic affective response of a user can potentially have at least dual purposes. Firstly, it could be used as a simulation tool for interior color design considering adequate color coordination required for the functions and placeness of a specific architectural space. For instance, an operation room in hospital is normally designed with white or green colors to invoke clean, calm, cold, and intense feelings required for the room functionality. This color coordination process could be simulated on-line with the proposed system in this research. Secondly, emotion-responsive interior space might be possible by utilizing controllable architectural components such as walls, floor, and ceiling the color of which could be changed depending on the occupant's mood or emotional state. If this visionary scenario is implemented, a therapeutic interior color adaptation will be possible lessening, for example, a depressive mood with complementary color scheme suggested by the system in this research.

Assessment Methods of Emotional Signals

According to the researches on human senses, our all five senses can be connected with those various signals such as physiological signal, bio-chemical signal, psychological signal, and behavioral signal. The data on human emotion is derived from these human senses (i.e. visual, auditory, olfactory, tactile, and taste). For instance, the physiological signals for various visual stimuli can be acquired using EEG (Electroencephalography), ECG (ElectroCardioGram), GSR (Galvani Skin Resistance), RSP and PPG (PhotoPlethysmoGram). Both measurement instruments and the systems which can manage, analyze, and evaluate the acquired signals have been developed. There also have been the development of an optimal bio-signal measurement method along with emotional criteria using psychological, linear and nonlinear chaos analysis methods.

Status of Emotional System Technology

An effective human-computer interaction allows emotional information to be communicated by the user in a natural and comfortable fashion. Emotional information also somehow needs to be recognized by the computer to support genuine interactions. At the MIT’s Media Lab, researchers are performing studies to give computers a capability of understanding natural modes of human communication. Those researches include the interpretation of signals such as facial expression, vocal intonation, muscular movement, gesture, respiration, and even autonomic nervous system signals. Groups of sensors are designed to track user behaviors that might signal frustration and to relate the user behavior with the current state of the computer. The Media Lab emphasizes that sensors are important part of an ‘Affective Computing System’ because they provide information about the wearer’s physical state or behavior. It is discussed that they collect data in a continuous way without having to interrupt the user.

In this research, we studied visual stimuli for measuring emotional states based on the protocols for necessary experiments. In Figure 2, we marked bold lines and shadings on the elements we selected as the elements for our proposing emotional measurement system. The graphical structure itself is organized hierarchically based on the AIP cube (Zelter, 1994) to represent various technologies involved in VR.

Our target VR system, mainly for demonstration purpose, is using a ‘monitor’ for visual display device in ‘presence’ category, ‘attribute and task modeling’ as a kind of object modeling in ‘autonomy’ category; a ‘mouse’ as gesture device, and ‘selection image’ as a method in ‘interaction’ category.

Scope of the System Development

The components and processes for the emotion-responsive VR systems developed in this research are as follow. 1) Construction of visual stimuli database
containing various pieces of visual art and images derived from well-known paintings providing necessary stimuli for emotional measurement based on the experiment protocols. 2) Extraction of emotional key word and the identification of color coordinate key words based on the tone and brightness of the selected painting by the user. 3) Establishment for an emotional color palette that determines a set of colors for VR adaptation. This process is done by using Expert Color Coordinate System based on a series of built-in heuristic rules to coordinate the colors of the participating objects in the target VR space which are floor, wall, ceiling, and furniture. 4) Construction of an adapted VR model by changing colors of those objects selected in the virtual interior system modeled by 3D Max and EON Reality Studio using an adaptive user interface provided on the web.

Color Palette - Keyword Image Schema

When people see a certain combination of colors embedded in an image, a common feeling could run through their minds. We choose color references which is called Kobayashi color scale. Because the color scale not only delivers a unique method of defining emotional color sense but provides in valuable insights into the art of using color. Moreover, the color research introduces a full range of colors for all moods and tastes then present eight psychological color types to assist human in putting their own color profile to practical use in the interior space.

![Fig.2. Keyword Image Scale (Kobayashi, 1990)](image)

Based on the Kobayashi color scale research that maps adjectives with these images and colors, a scale has been developed such as the Key Word Image Scale. With this scale, three axes have been introduced for obtaining an objective evaluation uninfluenced by value judgments based on personal preference, or by the context of assessment. The words and colors located at the same point along the warm-cool and soft-hard axes have the same images; it is the image that constitutes the connections between the word and the color. These image words are not only applied to colors but also can be applied to shapes, patterns, materials, interior design, fashion, and product design by providing a way of organizing images in a psychological view point. (Kobayashi, 1990)

Expert Color Coordination System (ECCS)

ECCS (Expert Color Coordination System) is for assigning palette colors identified through the previous image-based emotion inference process to a limited set of objects in the target VR model such as floor, wall, ceiling, and furniture. The identified emotional color palette extracted through interpreting selected visual image stimuli needs to be coordinated for each of the architectural components (i.e. floor, walls, ceiling, and furniture) to change their color attributes for the given VR building model. ECCS is automatically coordinating colors for each of the objects in the target VR space based on its internal inference system built upon interior design expert’s knowledge and experience.

ECCS is a rule-based color coordination system allowing domain knowledge to be represented as a set of heuristic rules which can specify a set of actions to be performed for the given conditions. There are some exemplary heuristic rules for this research. For instance, how to coordinate the color of each object in the VR house interior model could be arranged by the brightness of colors. Usually, dark color is applied to floor and light color goes to ceiling. Unlike the first stage of the research where the emotion system has an emotional keyword identified by the color scales, ECCS supports the final assignment of colors on the extracted color palette to each of the component objects in the given VR model.

Table 1. Summarized Interior (Living Room) Color Coordination Survey Result

| Hue         | Value | Chroma | Number of samples |
|-------------|-------|--------|-------------------|
| Floor       | YR/GY | 7.5    | 3.0               | 30                |
| Wall        | W/YR  | 9.2    | 1.8               | 30                |
| Ceiling     | W/YR/Y/B | 9.7  | 0.8               | 30                |
| Furniture   | YR/N/Y/W/GY | 7.5 | 2.6               | 86                |

To build ECCS, we used the result of another survey designed and implemented for identifying the most popular interior color coordination schemes of the apartment complex demonstration houses in Korea. Statistically justifiable preferred Munsell color codes for living room design of the 63 surveyed demonstrative apartment houses were picked up to extract color coordination rules for modifying colors of the floor, walls, ceiling, and furniture of the given VR model. Table 1 shows the summarized survey result including dominant hues, value and chroma ranges for each interior object.

The result of this survey is utilized to construct an expert system by using e2gLiteTM expert system shell available on the internet. This web-based expert system
shell allows a JAVA interface to process its input and output sets. With this application, the “if-then” rules extracted from the survey are captured into premise clauses with rule consequences. The rules are fired based on the internal logic of the inference engine. Each recommended action could have certainty factor after ‘@’ symbol if the value is to be assigned to a certain attribute with less than 100%. Goals are the attributes for which the inference engine seeks values. The following example is a part of the knowledge base for ECCS established in this research. Interior color coordination survey results in Table 2. provided reference for extracting rules and corresponding recommended actions.

Table 2. Exemplary Set of Rules and Goals for Constructing ECCS

| Rule | If | Then |
|------|----|------|
| R1   | If [the value of the color] = "lowest" and [the chroma of the color] = "highest" | assign the color to the floor’@85 |
| R2   | If [the hue of the color] = "VR" or [the hue of the color] = "GY" | assign the color for floor’@35 |
| R3   | If [the value of the color] <= 8.5 and [the value of the color] >= 6.5 and [the chroma of the color] >= 2.0 and [the chroma of the color] <= 4.0 | assign the color for floor’@50 |
| R4   | If [the value of the color] = "lowest" and [the chroma of the color] = "next to the highest" | assign the color to the furniture’@85 |
| R5   | If [the hue of the color] = "VR" or [the hue of the color] = "N" or [the hue of the color] = "V" or [the hue of the color] = "W" or [the hue of the color] = "GY" | assign the color for furniture’@35 |
| R6   | If [the value of the color] <= 6.5 and [the value of the color] >= 8.5 and [the chroma of the color] >= 1.6 and [the chroma of the color] <= 3.6 | assign the color for furniture’@50 |
| G    | Goal [the recommendation] | Goal [the action] |

The user can decide whether or not ECCS, an automated color assignment decision support tool, should be used. When the user does not want to rely on ECCS, the user can either manually allocate identified palette colors to the objects or just leave the task to the random color coordination algorithm. In case the user manually changes the color of each object, the color harmony is totally dependant on his/her own color preference. When ECCS is selected, a specially arranged color harmony is expected to emerge out of the given emotional color palette.

Figure 3 illustrates the mapping between the selected color coordinated key words (i.e. natural, romantic, clear) and the colors on the extracted palette. Each color in the palette is represented in the CMYK color system. Each identified emotional keyword is mapped onto four different colors on the color palette.

Table 3 shows the analyzed result of this survey mapping different paintings with emotional keywords such as natural, romantic, clear, casual, elegant, cool, dynamic, classic, and modern.

On-line survey has been performed to identify the necessary mapping between a series of paintings and the adjectives describing different feelings useful to represent users’ emotional responses. Total 10 well-known paintings were pre-selected for this purpose. Each of these paintings is considered to be iconic in terms of its representative characteristics of a specific emotional response. The selection process relied on public stereotypes regarding the perception of various paintings. 20 graduate students and experts in design
domain were asked to participate in the online survey to verify the validity of the prescribed mapping between the selected paintings and corresponding possible emotional responses and the result of this survey confirmed our assumption.

### 1. Select an image that you think the most “Natural”

Mark the radio button on the right to choose each image (Click to see larger image)

|   | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 | P14 | P15 | P16 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Natural | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Romantic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Clear | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Casual | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Elegant | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cool | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dynamic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Classic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Modern | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

![Fig.4. Online Survey to Establish a Set of Image Stimuli for Emotion Inference](image)

Table 3. Analyzed Result of the Online Survey with the Selected Well-known Paintings

| Image | Tone / Color Balance | Brightness | Emotional Keyword |
|-------|-----------------------|------------|-------------------|
| Image0 | Shadow – Color levels | Midtones – Color levels | Levels +10 Natural |
| Image1 | -12 0 -63 +10 | Peaceful |
| Image2 | -13 -23 -70 +10 | Reposeful |
| Image3 | +69 9 -50 +10 | Homey |
| Image4 | +48 -69 +47 +10 | Intimate |
| Image5 | +32 -10 +70 +10 | Naive |
| Image6 | -54 -18 +83 +10 | Earthly |
| Image7 | +31 +57 -78 +10 | Ecology |

Figure 5 shows the images chosen for the first set of visual stimuli to extract emotional keyword. It shows different paintings tagged with emotional keyword such as natural, romantic, clear, casual, elegant, cool, dynamic, classic, and modern. It also shows the color coordinate keywords elaborating the subtleness of the proposed emotion inference process.

### Controlled Visual Experiment

This step continuously performs a controlled experiment based on the user’s first image selection. From the selected original painting, the user is supposed to choose one image among many different tone-varied images.

Table 2. Second Set of Image Stimuli for the Controlled Visual Experiment

These second set of images are prepared by a systematic color tone variations of the chosen painting necessary for deriving a coordinate color combination. The color tone variation process is based on different balance levels described on the twelve-part color circle;
ranging from the primary colors (yellow, red, and blue) to the secondary ones (orange, green, and violet). A tone has three ingredients such as shadow, mid-tone and highlight. Each of the ingredients has the color levels which consist of cyan-red, magenta-green, and yellow-blue.

**Exemplary Demonstration of the System Implementation**

**1. Implementation process**

Figure 6 demonstrates an overall process of the proposed emotion-responsive Virtual Reality model focused on color adaptations. This process starts from the log-in point and ends its cycle when the user experiences or sees the adapted virtual reality model. In between, there are multiple steps to be followed such as the interpretation of the emotion-associated painting chosen by the user, the identification of the user’s emotion through the extracted color coordinate keywords using tone-varied multiple images for the chosen painting based on Kobayashi image keyword scale, a random or ECCS supported color coordination with the derived color coordinate palette, and finally, an automated color adaptation visualization process for the target objects in the original virtual model.

![Figure 6. Activity Diagram Showing the Proposed System’s Internal Process](image)

**2. 3D MAX - 3D SPACE MODELING**

To build an initial 3-D construct as the basis for the virtual reality model on the web, we used 3D MAX software. Figure 7 shows a snapshot of creating 3D objects in the interior space of an imaginary house. Those objects are internally organized in a hierarchy for further modification or changes of colors.

![Figure 7. 3D Modeling of Interior Objects](image)

**3. EON Reality Studio - Adaptive simulation**

As for the VR implementation environment, we chose EON Reality Studio for maximum performance and easy integration with the web environment. Figure 8 shows the exemplary processes where the created 3D objects are imported and further processed to become VR enabled EON objects the attributes of which are eventually manipulative on the web. Figure 9 demonstrates object color specification and the final VR simulation process.

![Figure 8. Color Node Tree and Color Control Window in EON](image)

![Figure 9. Simulation Window in EON](image)

HTML documents are designed to display the first and the second sets of image stimuli and to obtain a user’s response to them. To modify the color attributes of the chosen 3-D objects such as floor, wall, ceiling, and furniture, we generated Event nodes (shown on the left in Figure 10, which are embedded in a HTML document.
and associated with event Scripts and Objects. From this nodal representation of a virtual model provided by the Eon Reality Studio, a mouse click action on any of the ‘Event’ nodes (N01 -N07) can trigger the execution of the corresponding event Script to redefine color attribute for each of the 3-D objects represented as a material.

Adaptive VR Interface

As a demonstrative system implementation, we constructed a web-based emotion-responsive VR interface. In the beginning, user passes a log-on process by typing in his/her ID and password (Step 1). Secondly, the first set of visual stimuli shows up for the user to select an image out of them (Step 2). From the chosen image, a series of tone-differentiated images are displayed in the second visual stimuli interface for user’s selection (Step 3). The emotional keywords extraction and color coordination for VR simulation are processed internally. Eventually, the user is able to see the effect of his/her actions by experiencing an emotion-adapted virtual reality model in real-time (Step 4).
Conclusions

This study has suggested that emotional intelligence, being based on the emotional keyword-driven color schema necessary for magnifying the role of emotion in human intelligence, can be a subset of machine intelligence and that the way for man-machine interaction resembles the mode of inter-human interactions.

As an attempt to make an interactive and adaptive virtual space, this research tried to construct a methodological frame work to develop a user-centered VR system allowing interactions between the user and a virtual space beyond the conventional limitation of just imitating real world or using a straightforward web interface. The primary requirement this study tried to fulfill was to maximize the sense of emersion and satisfaction for using VR objects on the web, which has been partially explored through a color-adaptive VR model based on the identified user’s emotional state.

The advantages of the proposed emotion-responsive and color-adaptive virtual reality model are connected with its capabilities to invoke users’ active involvement and to explore a potentially new way of interior design in the future. The research has been theoretically based on the principles of emotion and colors as well as the emerging discussions on the emotion-responsive virtual space. The research process itself has been directly formulated through understanding the relationships between these theoretical bases. Eventhough the proposed set of keywords representing emotion-color relationships identifiable through a cognitive survey might not best reflect potential users’ emotional state, it could be, at least, a starting point to develop a human-centered virtual reality system supporting dynamic interactions between users and virtual spaces in the future.

References

1) Affective Computing Research Group (2000) Research on Sensing Human Affect [online]. Massachusetts : MIT Media Laboratory, available from World Wide Web:( http://affect.media.mit.edu/AC_research/sensing.html)
2) Cailin, B. (2001) Color Harmony for the web. Massachusetts: Rockport Publishers. Inc.
3) Daniela, B. and R.A, David Foell (1997). Designing Digital Space. Canada: John Wiley & Sons, Inc.
4) Frans, G. (1982) Evolution in Color. Pennsylvania: Schiffer Publishing Ltd.
5) Goodman, N. (1976) Languages of art: An approach to a theory of symbols. Indianapolis, IN : Hackett.
6) Kalawsky, R. S. (1993) The Science of Virtual Reality and Virtual Environments, Addison-Wesley-Longman.
7) Kalawsky, R. S., Bee S.T. and Nee S. P. (1998) Human Factors Evaluation Techniques to Aid Understanding of Virtual Interfaces. BT Technology Journal Third review version
8) Kobayashi, S. (1984) A book of colors . New York : Kodansha International Ltd..
9) Kobayashi, S. (1990) Color Image Scale. New York : Kodansha International Ltd.
10) Kobayashi, S. (1998) Colorist. Tokyo : Kodansha International Ltd.
11) Kunio Sato and Tesuya Hirasawa (1996) Taste Marketing.
12) Lee, S-Y. (1997) Virtual Engineering. Seoul, Korea : Chunmun.
13) Picard, R. W. (2000) Toward computers that recognize and respond to user emotion. IBM System journal, vol. 39, nos 3&4 : 705-719.
14) Picard, R. W., E. Vyzas and J. Healey (2001) Toward Machine Emotional Intelligence : Analysis of Affective Physiological State. IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 23, no. 10 : 1175-1191.
15) Porter, T. and Mikelides, B. (1976) Color for architecture. New York : Van Nostrand Reinhold.
16) Russel, J. A. and Fehr, B. (1987) Relativity in the perception of emotion in facial expressions. Journal of Personality and Social Psychology, 116(3) : 223-237.
17) Wollheim, R. (1987) Painting as an art. London, England : Thames & Hudson.
18) Zeltzer, D. (1994) Autonomy, Interaction and Presence. Presence, 1(1) : 127-132.