Validation of an AR-enhanced Advice System for Surgery with a Generic Phantom.

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Abstract

We describe the validation of a novel visual advice system using a generic phantom. The color selection is based on a convex-hull based analysis of the occurring colors. The visual advice system for Navigated Control (NC) is used as an example for a medical system employing different modes. Our validation study shows that a visual advice system using colours outside the convex hull of the underlying scene colors significantly enhanced the perception of the displayed cues.

Introduction

The motivation for this study is to ensure the save use of medical technology in the Operating Room (OR). Concerning the example of Navigated Control (see below), human-computer-interaction is an important safety issue. In particular, the goal of our study is to improve human-computer interaction by studying the perception of color cues. We work in an interdisciplinary team consisting of psychologists, physicians, and computer scientists.

Navigated Control and Mode Error

Our main hypothesis is that a visual advice system using colors outside the convex hull of the colors in the underlying scene provides stronger visual cues and does not distract the surgeon too much. Based on the framework for the evaluation of image guided interventions (Jannin & Korb, 2008), the theoretical background and methods used to evaluate a visual advice system for the Navigated Control system (NC) (Lüth et al., 2001) will be described in the following passage.

21. **Systems description and indented use:** The use of different modes is common in modern machines (Monk, 1986). They represent different states or functions of a system (Andre & Degani, 1997). NC is a surgical navigation system with two different modes (Lüth et al., 2001). In the “navigated controlled” mode, the surgical milling instrument automatically switches off outside a predefined region of interest. The region of interest is defined preoperatively with segmentation. If the tip of the tracked instrument is within this region, the instrument performs the milling, outside this region the instrument is switched off, even if activated by the surgeon with a foot pedal. In the “free mode” the surgeon can use the navigation and is not limited in the use of this surgical instrument in the situs. This NC system is currently evaluated in clinical patient trials (Strauß et al., 2006).
22. **Surgical context and intended use:** NC is used for milling bone e.g. in mastoidectomies, dental implant drilling, and spine surgery.
23. **Assessment Level:** The authors were interested in the development of a visual advice system (Level 1 of the Framework by Jannin et al., 2008)
24. **Criteria and measures:** The question if the user is aware of the current mode is a crucial safety issue during the use of a system is (Andre et al., 1997). In the case that the same user input has different consequences in different modes (Norman, 1981), unawareness of

the current mode can lead to an unexpected and unwanted output of the system. In the case of NC this can lead to a serious complication for the patient. Therefore an adequate visual advisory system that enhances modes awareness reduces the risk of mode errors. In the case of NC, this system is integrated into a surgical microscope.

25. **Study conditions:** The visual advisory system is studied in a surgical demonstrator OR. This makes the study scenario more realistic and also more controllable (Jannin et al., 2008). In the study, a generic phantom is used (Geißler et al., 2009) similar to the phantom described by Möckel, Grunert und Korb (2007).
26. **Assessment methods:** To evaluate our hypothesis, we measure different variables with a questionnaire such as perception and associated danger. The self-developed scale for the perception of the visual advice system contains 2 items (contrast and visibility) with a Likert scale.

Convex Hull

The human visual system relies on low-level perceptual mechanisms to highlight and select specific parts of the sensory input stream. Important factors for low level perceptual processing are for example color, size and orientation of the feature (glyphs) and density and regularity of texture elements (Bartz et al., 2008). If chosen carefully, colors can be used, to let features pop-out (Healey et al., 1996). An important base to analyze the colors for a visual advisory system are color spaces like the CIE L*a*b* model[1] , because they provide measurability.

Ware (2004) proposed that a signal color used in images should lie outside of the convex hull of all occurring colors in the image. Based on Ware`s work (2004) we use, as technical base for the color analysis, the Color-SpaceCAD plug-in for Photoshop (Neophytou et al., 2008). A picture is analyzed and the convex hull of the colors in L*a*b-space is computed. This software can handle the most important pixel formats.

For an analysis of occurring colors in videos, we decompose the videos into single frames. The color of each pixel given in the RGB color space is converted to the CIE L*a*b* color space and the convex hull is henceforth computed. A convex hull of spanned by a subset of colors contains all used colors and all possible combinations of these colors.

The appropriate signal colors are found outside of the convex hull. The convex hull of the separate images can be saved with the intern gamut-library in an XML format. Using these saved convex hulls, it is possible to evaluate videos by analyzing each individual frame and aggregate the saved convex hulls into one single convex hull of the video[2]. To obtain a more general convex hull of the study phantom, we combine the convex hull of a number of videos of the phantom.

The resulting color cues can be overlayed by the surgical microscope Pentero (Carl Zeiss Surgical, Oberkochen, Germany) as a visual signal. We use the SVGA input and a channel for the data input. Carl Zeiss Surgical provided a software toolkit, which enables us to overlay the visual output of a computer (PAL signal) directly into the surgeons field of view.

Methods

The challenges of evaluating systems used in image guided interventions are described by Jannin and Korb (2008). Based on their guidelines we chose a study design that includes a realistic task for the participants as well as sufficiently high control of the conditions.

[1] A perception-oriented color space in a norm chromaticity diagram from the combinations of red, green and blues (x, y, z)

[2] As a further reference value for the salience, the distance to the convex hull is appropriate. The further the signal color is, the larger the degree of salience removed from the convex hull within the color space.

In a within group design, 30 medical students performed the study task with different valuated visual advisory systems. The order of the versions with signal colors inside and outside the convex hull is completely randomised. Previously, we recorded different videos of our study phantom on an operating table. We did the color analysis of the videos and chose one pair of colors (for the signals NC ON/OFF) from inside the convex hull and one from outside. The signal was positioned in the lower right of the microscope. The evaluation was done by a self-developed and validated questionnaire. The subjects watch the videos through the OPMI Pentero (Carl Zeiss Meditec, Jena, Germany) and filled in a questionnaire directly after each video.

Results

The reliability of the self-developed scale is very good for the symbol NC ON (Cronbachs alpha within the convex hull = .81; Cronbachs alpha outside the convex hull =.87) and NC OFF (Cronbachs alpha within the convex hull = .87; Cronbachs alpha outside the convex hull =.88). The signal outside the convex hull for NC ON was significantly more visible ($p < .001$). This effect was found for the individual items as well. The signal outside the convex hull for NC OFF was also significantly more visible ($p = .001$). This effect is found for the individual items as well. The urgency and the associated danger of NC OFF were significantly higher for the signal outside the convex hull (urgency $p < .001$ and associated danger $p < .001$). There is no significant difference in the rating of the distraction between the versions inside or outside the convex hull.

Discussion

Visual computing with perception research is essential to design effective augmented visual advice systems for surgery. The type of visualization makes a significant difference in terms of effectiveness with the interaction. Nevertheless visualization and interaction processes in medical systems have to be analyzed further to take advantage of their power. The study results provide a basis for further studies and will give important cues for further studies of a visual advice system. The study shows that a visual advice system that is using colors outside of the convex hull significantly enhances perception of visual signals, NC ON and NC OFF in our case.

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