COLOR USABILITY ON AIR TRAFFIC CONTROL DISPLAYS

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Modernization of Air Traffic Control (ATC) display systems includes increased use of color to code information. While colors can enhance display designs, human factors issues like legibility and salience manipulation are still problematic. Here, we address some of the potential usability issues with integrating traffic and advanced weather information on controller displays. We argue that color palettes that are not specifically designed for layered data and a large number of objects can create legibility and salience problems. We discuss the use of luminance contrast to manipulate salience and present some empirical data showing that air traffic controllers display large individual differences in their preferred brightness settings. We argue that user adjustments of luminance contrast for salience manipulation must be severely constrained in future ATC displays. We present a prototype color palette that uses color-coding to prioritize display information while maintaining good legibility.

INTRODUCTION

Current FAA upgrades of Air Traffic Control (ATC) facilities include a move from old monochrome radar displays to modern situation displays with color capabilities. With these new capabilities, designers are increasing the use of color in the representation of display objects.

Uses and Affordances of Color

New uses of color on ATC display systems include representation of such display objects as airspace maps, symbols for aircraft, weather (precipitation) information, and alphanumeric data. The display of advanced weather information like storm movements, winds, and short-term forecasts on controller situation displays is a new area of potential use for color-coding (Figure 1). Weather phenomena contribute to safety hazards and reduced airspace operational efficiency.

Advances in processing power and weather radar technology have produced an increase in the availability of advanced weather information in en route and terminal facilities. Currently this information is only displayed on traffic flow managers' and supervisors' workstations. However, researchers are exploring the potential benefits of displaying this additional weather information on controller displays (Ahlstrom, Keen, & Mieskolainen, 2004).

Color-coding has several potential advantages in an ATC information display. It can indicate class membership of data elements (e.g., which aircraft are being managed by which controller). Other examples from operational software and research prototypes include color-coding to represent traffic flows, emergencies, weather hazards, and the status of military special use airspace (Ahlstrom, Rubinstein, Siegel, Mogford, & Manning, 2001). It can provide visual grouping and pre-attentive segregation of spatially distributed, related graphic elements (e.g., all symbolic and alphanumeric data relating to a new trajectory clearance). It also can contribute to a salience hierarchy that visually segregates more urgent display information from less critical context information.

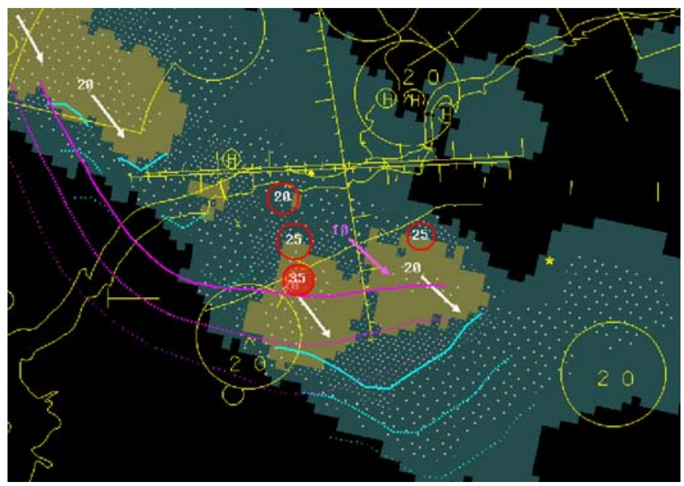

Figure 1. An illustration of precipitation levels and advanced weather information used in the simulation. Precipitation Levels 1-3 are coded 'blue' and Levels 4-6 'brown'. Sparse stipples represent Level 2 ('blue') and 5 ('brown'). Dense stipples represent Level 3 ('blue') and Level 6 (not in picture). Unfilled red circles indicate wind shear and semi-filled red circles indicate microburst. The white arrows denote storm cell motion. Current storm cell position is solid magenta, and extrapolated positions (10 and 20 minutes) are dotted. Current gust front position is solid pink, and extrapolated positions (10 and 20 minutes) are dotted.

Human Factors Concerns

While color-coding has potential benefits, it presents several human factors challenges. Legibility, salience manipulation (clutter avoidance), and color recognition are the main usability issues at stake. The first two are strongly affected by the reduced luminance contrast of some symbol/background color combinations. As more graphic symbols and areas are color-coded, the possible combinations of foreground and background colors rapidly increase. Aircraft symbols and alphanumeric data move and must be readable on all weather backgrounds and fixed background areas.

The design challenges are further complicated by prior practice in ATC facilities. Some important parameters of the viewing environment have historically been adapted by the facilities for their local operations, and users have been able to make some kinds of color adjustments. Most operational ATC workstations are equipped with independent controls for brightness settings of display objects. By varying the brightness of display objects, a controller can emphasize information that is important for the task (e.g., aircraft targets), and de-emphasize other less critical information (e.g., map details). While prior research has explored the use of colors and graphics for interface design (Ahlstrom et al., 2001), very little has been reported on individual user preferences in salience manipulation. With an increasing number of potential symbol/background color combinations, users risk producing sub-optimal usability.

Given these concerns, it may be necessary to constrain the users' options for color adjustments in new ways. One possibility would be for designers to provide fixed color palettes designed for optimal usability. Previous researchers have proposed frameworks for optimal color palettes that can be used for simultaneous presentations of traffic data and system information (Reynolds, 1994; Van Laar, 2001).

Although frameworks for the use of color palettes in situation displays have been proposed, very few ATC operational systems have been developed using these recommendations. Color palettes that are not specifically designed for layered data and a large number of color-coded display objects can create legibility and salience problems. There is a growing need for pre-determined, well-designed color palettes that use color-coding to prioritize display information.

In the present paper, we address some of the potential usability issues with integrating advanced weather, traffic, map, and other information on controller situation displays. We present some empirical data showing that air traffic controllers exhibit large individual differences in their preferences for luminance-contrast settings. Based on those observations, we argue that user adjustments of luminance contrast for salience manipulation may need to be constrained in future displays.

METHOD

Weather Information Study: Air Traffic Controllers' Luminance Contrast Settings

We obtained our data about controllers' individual preferences for luminance contrasts as part of a recent, larger study of display of weather information in ATC. In this human-in-the-loop simulation, we investigated the operational impact of providing Terminal Radar Approach Control (TRACON) controllers with advanced weather information at their workstations. Eleven full-performance level (highly-skilled, current) TRACON controllers participated in the simulation (*M* experience=12 years). Figure 1 shows an illustration of the weather data on the situation display used in the simulation. The traffic, map, graphics, and the operational controls simulate displays in use in modern TRACONs. For weather scenarios, we used pre-recorded weather data from the Integrated Terminal Weather System (ITWS), a new system coming into use at larger TRACON facilities. The controllers' display allowed independent manipulation of display of six levels of precipitation. Controllers could also display symbols indicating storm cell movements, gust fronts, wind vectors, and short-term (10-20 min) forecasts of storm cell movements.

Prior to participating in the simulation, controllers received a full day of training on the sector, traffic flow, and use of weather information. During this training day we required that controllers adjust the settings on their situation display for the simulation. These adjustments included font size, the location of lists, and individual brightness levels for display objects. At the end of the training day, after adjusting all display properties to levels that the controller was ready to use operationally, controllers saved their individual operational 'preferences'. These were used during all subsequent simulation runs.

RESULTS

Individual Preferences for Brightness Contrasts

Figure 2 shows the means and ranges of eleven controllers' individual preferences for the luminance contrasts of 12 display objects on the 'brown' precipitation background. The luminance contrast statistic in Figure 2 is the difference of the logarithms of symbol and background luminances, log (Y_{sbl}/Y_{bkg}). There were large individual differences among the controllers' luminance contrast preferences.

Even more striking, the individual settings represent visual appearances that vary greatly among controllers. For example, while most of the controllers chose to give the components of the aircraft track and the aircraft data block much higher luminances than the background (i.e., high luminance-contrasts), others did not. The former gave high salience and legibility to the symbols and alphanumeric data for the aircraft that they were controlling. The latter gave more nearly equal salience to the aircraft data and the map and control symbology.

Aircraft Location Cluster. The location of each aircraft is marked with a cluster of symbols representing several aspects of the radar information. The Search Target ("Primary Target") represents the aircraft location indicated by the selected radar. The Beacon Target represents the calculated position based on the transponder signal received from the aircraft. The Controller Jurisdiction Indicator ("Position Symbol") indicates which controller is currently responsible for separating the aircraft from other aircraft. The History Trail indicates the previous locations of the aircraft by a series of dots. The maximum number of dots is ten, but controllers commonly use three or four to avoid clutter.

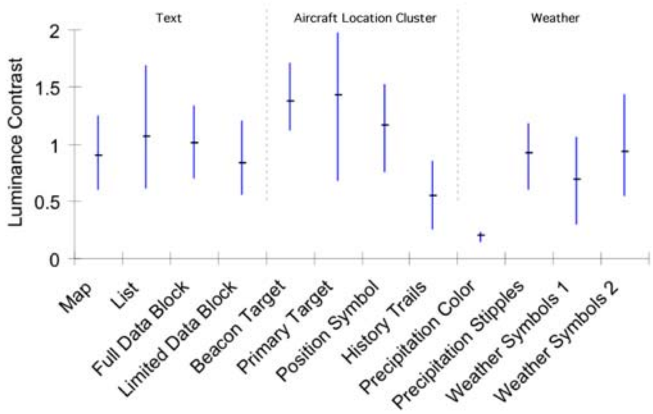

Figure 2. Means and ranges of the 11 controllers' preferences for the luminance contrasts of 12 display objects on the precipitation 'brown' background. The luminance contrast statistic is the difference of the logarithms of symbol and background luminances, log (Y_{sbl}/Y_{bkg}). Weather Symbols 1 includes symbols for microburst and windshear, and Weather Symbols 2 includes symbols for storm motion, gust front, and wind vectors.

Our controllers showed a wide range of preferences for salience of the various Aircraft Location Cluster components, as indicated by their settings of the luminance contrasts (Figure 2, center group). Image clips of several of their settings are shown in Figure 3. The top clip shows a case in which the controller position symbol nearly obscures the other components, which are very faint. The middle clip shows another extreme, with the high-luminance-contrast Primary Target making the Position Symbol very hard to read. The bottom clip is more balanced with all the components (except perhaps the History Trail) clearly legible.

Precipitation. The six intensities of precipitation are indicated by two solid fill colors ('blue' and 'brown') and two densities of superimposed stipples on each. Here, too, our controllers had a wide range of preferred luminance contrasts (Figure 2, right-hand group).

The more extreme settings have potential usability problems. In the left clip of Figure 4 the controller's luminance contrast of the 'blue' is so low that the boundaries of that region (outside of the clip) are hard to detect against the black background. Another controller (Figure 4, right clip of figure) set both the 'blue' and 'brown' at higher luminance contrasts, making their edges clear, but leaving some of the weather symbols illegible.

Weather symbols. The controllers also had very different ideas about the salience of the weather symbols. In some cases (Figure 5, bottom of figure) symbols indicating wind direction were illegible due to very low luminance contrast. Symbols warning of microbursts were hard to see in another case (Figure 5, center of figure). Failure to notice a microburst indication could have serious consequences.

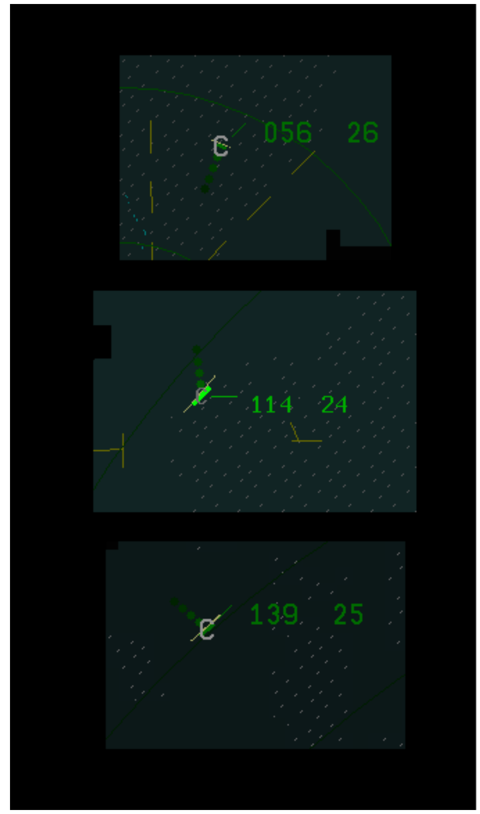

Figure 3. Image clips of three controllers' luminance-contrast preferences for components of the Aircraft Location Clusters.

DISCUSSION

In older monochrome displays controllers often used the independent luminance controls of the symbols for air traffic and static context information to turn down the latter to prevent the context from distracting their attention from the traffic. Preferences ranged from moderate, clearly visible context to nearly invisible. With these relatively simple displays it seems unlikely that the users' adjustments caused serious usability or safety problems. In current and future color displays, on the other hand, there is potential for serious problems. Even without additional symbology the problem

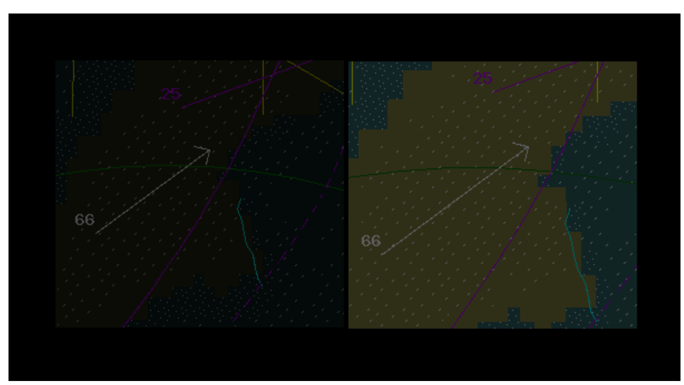

Figure 4. Image clips of two controllers' luminance-contrast preferences for precipitation intensities.

of assigning appropriate luminances is challenging due to the different luminance gamuts at different chromaticities on the color monitor (Figure 6). The maximum available luminances of saturated blues, reds, and purples are much lower than those of greens, yellows and grays. This unavoidable structure of the monitor gamut imposes severe tradeoffs between the discriminabilities of coding colors and luminance contrasts of the symbols. We need a palette that achieves good margins of legibility and color identification for all symbol and background color combinations, while helping users manage their attention through manipulation of luminance contrasts. Color-coded precipitation areas and caution-and-warning coding make the problem even more difficult.

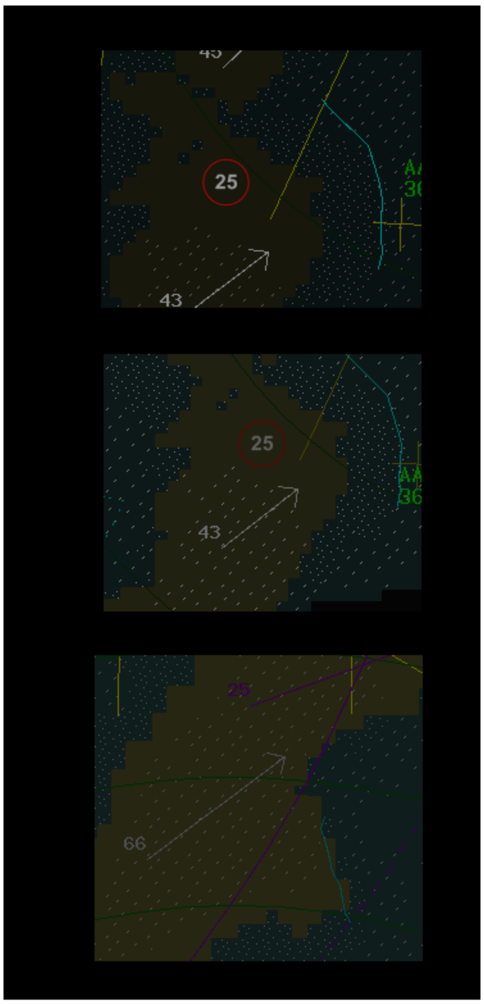

Figure 5. Some controllers' settings of luminance-contrasts of weather symbols produced poor legibility or inappropriate salience.

Risks of User Adjustments of Brightness in Color Displays

Regarding the preferences we observed, the more extreme cases of emphasizing one component and de-emphasizing the others have possible operational risks. Changes in the status of the de-emphasized components may pass unnoticed, especially if the contrast is low and the controller's attention is directed to other aircraft. The most obvious case of this was the faint microburst symbols (Figure 5, center). Microbursts are extremely hazardous in terminal area operations.

It is perhaps not surprising that some of the controllers' settings for unfamiliar weather graphics were suboptimal. The more extreme settings for familiar traffic symbols are harder to understand. In the case of the hard-to-read Position Symbol, for example, under unusual circumstances controllers might confuse one of their own aircraft for one "owned" by another controller.

It is possible that risks could be minimized by standard settings of relative luminance contrasts among the components. Some standardization of color usage would seem to be appropriate, to guarantee legibility and adequate salience of safety-related information. The diversity of settings among our controllers suggests that the settings would need to be developed by a careful design process. That process should include human factors experts and domain experts/users. Display of complex weather information on controller displays is so new that there is likely to be less firmly established personal preference among controllers to be overcome, on the one hand, but less user experience to draw upon in designing reliably usable graphics.

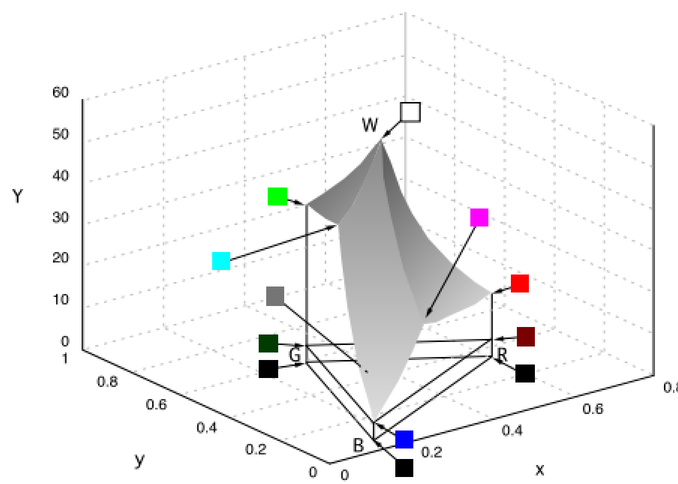

Figure 6. Gamut of a color monitor in xyY coordinates. The maximum luminance (Y) obtainable in different regions of color space varies by a factor of 15.

While some degree of user adjustment of luminances may still be possible with complex color palettes this has yet to be proven. Complicated constraints will have to be imposed to prevent poor legibility and clutter from posing usability and possibly even safety risks.

Prototype Color Palettes

With the above considerations in mind, we have developed prototype ATC color palettes (Figure 7) that:

- provide sufficient luminance contrast for legibility of all symbols and alphanumerics on all backgrounds,
- manipulate luminance contrasts to produce a hierarchy of salience that corresponds to the urgency of the coded data elements.

In accord with guidelines (FAA HFDS, 2003) they also color-code graphic elements only for specific operational purposes - grouping, caution and warning status, and category labels.

The most prominent differences between Figure 1 and Figure 7 are replacement of the six textured precipitation levels with three solid, color-coded levels and de-emphasis of some information by decreased use of high contrast, saturated colors. The former makes the codes for levels of precipitation correspond to coding of weather in the cockpit displays of the aircraft . The latter allows increased salience of aircraft symbols and local weather hazards. Red indicates extremely hazardous weather (severe turbulence, multiple hazards), yellow hazardous weather, and green indicates less precipitation. Under current procedures pilots decide whether to penetrate weather. Most pilots avoid penetrating areas coded red when at altitude. They will sometimes do so if close to the runway and preceding aircraft have successfully penetrated (Rhoda & Pawlak, 1999).

Our salience hierarchy reflects the urgency of various data elements (NASA Color Usage Website, 2004), with flight hazards (weather, traffic) getting highest priority, followed by the controller's aircraft and on down to static context information (map, range rings, etc.).

Within this framework user-adjustments of color should be constrained to maintain the hierarchy of salience that reflects the relative urgency of data elements. The luminance contrasts of groups of graphic elements might be adjusted over limited ranges to accommodate variation in individual displays, viewing environments, and users' individual preferences, but not enough to defeat the purposes of the salience hierarchy or threaten legibility.

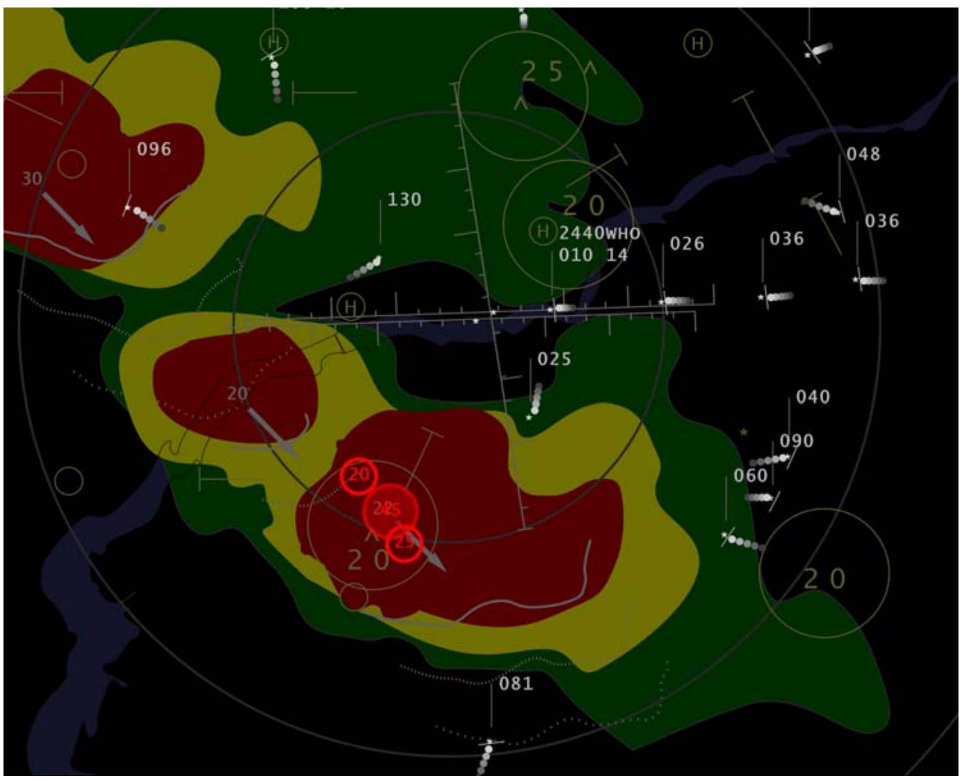

Figure 7. Prototype TRACON display illustrating a color palette supporting legibility, color identification, and attention management. The six precipitation levels of Figure 1 have been compressed to the three levels commonly displayed on cockpit weather displays.

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