Improving Symbol Salience in Augmented Reality

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Abstract: In augmented reality applications, users may experience difficulty in finding virtual symbols placed over images of the real world whenever the colour of the surrounding background becomes similar to the symbols' colour. We investigated a set of adaptations to make virtual symbols more salient from the background, while maintaining the original semantics, and conducted a study to evaluate user preferences about the adaptations, which revealed that adding a border to the symbols was favoured by the majority of the participants. Next came colour luminosity adjustment and changing the colour of the letters inside the symbol; however the latter was only preferred against symbols with no adaptation, that is, it was never chosen when competing with the other adaptations. Enlarging the symbol was the least selected adaptation, followed by having no adaptation at all. These results suggest using adaptations based on border addition and colour luminosity adjustments in the representation of virtual symbols for augmented reality.

1 INTRODUCTION

Augmented Reality (AR) applications place graphical symbols over images of the real world to provide extra information to the user. As there is no control over these images, the virtual symbols may not be detected by the user because, for instance, their colour is similar to the background colour. This problem is more acute in outdoor AR, where visual information and lighting conditions can change faster (Gabbard et al., 2007).

One solution to this problem is to dynamically, and continuously, adapt the graphical attributes of the symbols so that they become more distinguishable from the real world image. However, these adaptations should not drastically change the virtual symbols as the user will most probably get confused and disoriented. Therefore, the adaptations should make symbols more conspicuous, maintaining, nevertheless, the original semantics associated with them.

The literarure proposes several approaches to mitigate the problem of legibility of graphical symbols in AR applications. Kalkofen et al. (2009) proposed techniques based on the use of artificial colouring when objects have low contrast with their surrounding background. In Gruber et al. (2010) the colours of both the virtual objects and the real world images were automatically harmonised based upon aesthetics guidelines.

Besides graphical symbols, text can be used to provide extra information in AR applications. Gabbard et al. (2007) investigated the influence of outdoor lighting conditions in text readability and tested algorithms to improve text contrast relative to the background image. Leykin and Tuceryan (2004) focused on pattern recognition models to identify regions in which labels should be hard to read due to interference caused by background textures. They used grey scale images and computed the contrast between the text and the surrounding real world image, and ultimately moved the labels to regions allowing higher readability.

As our aim is to adapt graphical symbols so they become distinguishable from the real world image, without moving them to new positions, and without modifying real world images, it is important to find out which characteristics are prone to make graphical symbols more conspicuous.

Wolfe and Horowitz (2004) made a survey of the attributes that guide visual search and concluded that colour, motion, orientation, and size undoubtedly guide human attention. Almost the same attributes were studied by Paley (2003) to distinguish the text in a transparent overlay window from the background text. For example, he suggested drawing outlines around each letter. Regarding the adaptation of graphical symbols, Nivala and Sarjakoski (2007) proposed the drawing of a border around points of interest in maps.

The goal of this research is to investigate adaptations that improve the distinctiveness of graphical

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symbols superimposing real world images, while preserving the original semantics. To this end, we propose a set of adaptations that make controlled adjustments to the symbols and discuss the results of a study to assess user preferences in scenarios in which the colours of unadapted symbols and most parts of the real world image were purposefully very similar.

The paper is organised as follows: in Section 2 we describe the symbol adaptations and how we did initial tuning; Section 3 is about the user study and in Sections 4 and 5 we present and discuss the results; Section 6 is for conclusions and future work.

2 PROPOSED ADAPTATIONS

Our goal is to use a set of symbol adaptations and test if these ameliorate the detection of graphical symbols in AR applications, while maintaining the semantics associated to the symbols.

We considered as base symbol (BA) a square filled with a uniform colour, containing one or two black characters (letters or digits). This symbol shape is popular in applications to find points of interest, as shown in Nivala and Sarjakoski (2007). Furthermore, this type of symbol is prone to be difficult to distinguish with a variety of backgrounds, and, thus, was found convenient to test the adaptations.

Given this base symbol, we investigated four types of adaptation (described next), developed a software prototype built in Java using NyARToolkit (ARToolWorks, 2012), and conducted an iterative empirical evaluation with members of the research team to test and fine-tune the adaptations. To decide if a symbol should be adapted, the dominant colour (having the highest frequency) of the symbol is compared with the dominant colour of a rectangular image region that encloses the symbol. If the absolute difference between each of the three RGB colour components is less than a threshold, the two colours are considered similar, and when this happens the symbol is adapted.

The four major types of adaptation were the following: adding a border around the symbol (BO), adjusting the colour luminosity (CO), enlarging the symbol (EN), and changing the colour of the letters or digits inside the symbol (LE). Figure 1 shows examples of the adaptations and minor variants.

BA BB BW C1 C2 EN LW

Figure 1: Examples of base and adapted symbols.

As in Nivala and Sarjakoski (2007), we also applied a *border around the symbols* to make them more conspicuous. We considered two neutral colours for the border, black and white, to avoid misleading interpretations that could be introduced by the use of colour (Silva et al., 2011). Regarding the border width, we settled with $1/8$ of the size of the base symbol. In Figure 1 these variants are identified as BB and BW.

As mentioned earlier, changing the colour of a symbol could be interpreted as a change in its meaning, thus we chose to *adjust the colour luminosity of symbols* to enhance the contrast with the background. Our approach was to draw symbols slightly lighter when the background is dark, and to draw symbols a bit darker when the background is light. To adjust the luminosity of a symbol, the dominant RGB colour component or the co-dominant components were modified by adding or subtracting a constant value, ensuring that a dark symbol became lighter, and vice-versa. For the CO adaptation, we tested two constant values, 50 and 100 (in a scale from 0 to 255), corresponding to variants C1 and C2 in Figure 1.

As mentioned previously, Wolfe and Horowitz (2004) included size as an attribute that undoubtedly guides human attention. This conclusion is also confirmed by our common sense. Therefore, one of our adaptations is the *enlargement of the base symbol*, with a factor of $3/2$ relative to the size of the base symbol. This adaptation is identified as EN in Figure 1.

Finally, to increase the contrast of the letters inside the symbol, when both the background and the symbol have a dark colour, the *letters on the symbol are depicted in white*, shown as LW in Figure 1. Since the base symbol has black letters, we did not consider the adaptation that would turn white letters into black letters on symbols with light colours.

3 USER STUDY

We set up and conducted a user study to empirically evaluate the adaptations shown in Figure 1, in scenarios in which base symbols had colours similar to the surrounding real world image. In these circumstances we assumed that the adaptations would improve symbol salience, and hypothesised that users will prefer the adapted symbols rather than the base symbols.

A total of 55 *participants*, 22 men and 33 women, volunteered to the study. 14 were master or PhD students, 22 were undergraduate students, and 19 did not finish high school. Their ages ranged from 20 to 79 years and the median age was 26. We recruited from social contacts and offered no monetary reward.

Concerning the *apparatus*, the study was carried out indoors to minimise influences in symbol perception due to strong daylight. A laptop was placed on a desk in front of the participant and the screen was positioned to allow a clear view of its contents. A presentation software was used to show predefined sequences of images according to specific timings.

Participants were asked to perform counting and preference *tasks*. In the first task, a photo of buildings or trees with scattered symbols overlaid was presented to a participant for 8 seconds, during which s/he had to count the symbols. The position of the symbols varied with the photo to prevent learning effects. When the photo disappeared the participant reported the number of symbols found. The preference task immediately followed the counting task and had no time limit. The researcher started by showing the same photo that was used for the counting task and then asked the participant for the preferred symbol adaptation.

We set up the user study according to a repeated measures *design*, that is, in each trial the same participant was exposed to different conditions. We manipulated two independent variables, namely symbol adaptation and background. We tested all adaptations proposed in this paper plus the case with a base symbol (with no adaptation), as shown in Figure 1. Regarding the background variable, we distinguished between predominantly dark and light backgrounds over which the symbols were placed. We used two sets of photos representative of natural scenes with shadows or poor illumination versus bright sunlight, respectively. The positions of the symbols was carefully chosen to simulate adverse situations in which the colour of a symbol was purposefully very similar to the colour of its surrounding area in the background image, as can be seen in the examples in Figure 2.

(a) (b)

Figure 2: Dark and light backgrounds with symbols overlaid.

The manipulations of adaptation and background were organised in five blocks, as shown in Table 1. We note that the tests range from T01 up to T21 because we are reporting here part of a larger study. The order of exposure to blocks A, B, C, and D, was randomised, and block E was always executed last by participants.

Blocks A, B, C and D were designed to test separately each of the four major types of adaptations in Section 2. For instance, in block A, a background photo was presented first with base symbols overlaid,

Table 1: Tests with dark and light backgrounds.

Block	Adapt.	Variants	Dark	Light
A	Base	BA	T01	T03
	Border	BA,BB,BW	T02	T04
B	Base	BA	T07	T09
	Enlarge	BA,EN	T08	T10
C	Base	BA	T12	T14
	Colour	BA,C1,C2	T13	T15
D	Base	BA	T18	—
	Letter	BA,LW	T19	—
E	Mixed	BA,C1,C2,EN,BB,BW,LW*	T20	T21

*The LW adaptation was not tested with light backgrounds.

in test T01, and then, in test T02, with base symbols mixed with symbols with black or white borders (BB and BW variants of the border adaptation). In block E, all symbol adaptations competed for the participants' attention. The total number of symbols was always 13 and the percent of symbols per adaptation was proportional to the number of adaptations involved.

The dependent variables were symbol count and preferred symbol adaptation. Measurement of preferences was only carried out for tests that featured multiple adaptations and we note that the total number of tests varied with the adaptation type, meaning that preference results will be expressed as proportions.

Regarding the *procedure*, a trial started with an introduction about the research. Next, a questionnaire was filled out by the researcher according to the answers given by the participant about age, gender, and academic training. The initial formalities were completed with the adjustment of the laptop screen position to the height of the participant.

The core of the study comprised five blocks of tasks, each taking 4 to 5 minutes to complete. In blocks A, B, C, and D, the participant was exposed to a dark background image (see example in Figure 2a) with only base symbols overlaid, and performed a counting task. The same image, with symbols scattered in different places, was shown to the participant but this time the symbols were adapted as described in Table 1 and both counting and preference tasks were carried out sequentially. Within the same block (except in block D), a similar procedure was executed for images with light backgrounds (see Figure 2b). In the final block, E, counting and preference tasks were carried out for two images, with dark and light backgrounds.

4 RESULTS

Participants expressed their *symbol adaptation preferences* according to the proportions in Figure 3. Each proportion was obtained by dividing the number of opinions favourable to an adaptation by the total opportunities in which participants could have chosen that adaptation. For instance, in the most popular adaptation, BO or border around symbols, there were 4 tests (see BB and BW in tests T02, T04, T20, and T21 in Table 1) $\times$ 55 participants = 220 opportunities, and in 200 of those (91 %) participants preferred it, rather than the base symbol or any other adaptation.

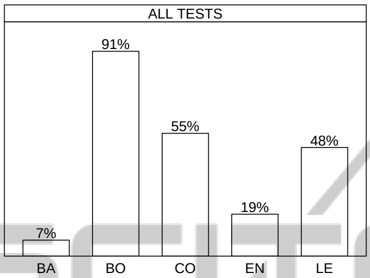

Figure 3: Preferences by major type of adaptation.

A test of equal proportions showed significant differences in the proportions in Figure 3 ($p \ll 0.001$). Two-sample tests for equality of proportions revealed differences for all pairs of adaptations ($p \ll 0.001$), except for $\langle$CO,LE$\rangle$. Thus, and given that the proportion for the BA adaptation was the smallest, we can accept the hypothesis that the adaptations proposed in this paper are preferable to symbols with no adaptation.

We applied two-sample tests of equality of proportions to each adaptation variant in the light and dark background conditions (see Figure 4), which revealed significant differences in preference proportions ($p \ll 0.001$), except for the EN (enlarge) variant. Thus, we can conclude that the predominant luminosity of the background image influences participants' decisions about the preferred symbol adaptation.

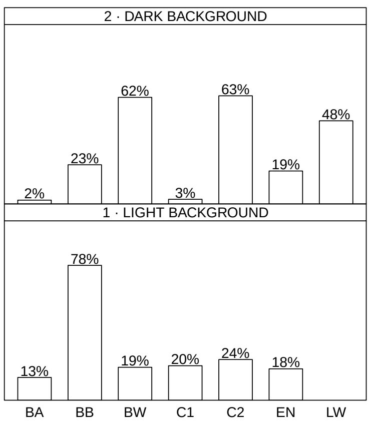

Figure 4: Preferences by adaptation variant, per background.

The analysis of Figure 4 further reveals that with light backgrounds the preferred adaptation was adding a black border around symbols ($p \ll 0.001$ compared to each of the other adaptations). With dark backgrounds, both BW and C2 had the highest preference proportions ($p < 0.015$), but it was not possible to reject the hypothesis of their equality.

We also analysed adaptation preferences in two contexts: the first comprises tests in blocks A, B, C, and D (see Table 1) in which participants were exposed to base symbols plus one type of adaptation (and its variants); the second context covers tests in block E, in which all adaptations competed simultaneously for the participants' preferences. Figure 5 shows differences between the proportions of each adaptation variant in the two contexts ($p < 0.002$, two-sample tests of equality of proportions), except for the BB condition, for which the proportions were likely the same.

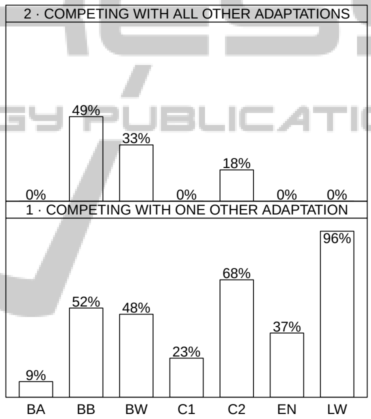

Figure 5: Preferences by adaptation variant, per context.

Curiously, when participants were exposed to all adaptations at the same time (Figure 5, top) no one chose BA, C1, EN, or LW, which suggests the other adaptations were the favourites. Thus, to check if the order of preferences in this context was BB, then BW, and lastly C2, we applied two-samples tests of equality of proportions to $\langle$BB,BW$\rangle$ and $\langle$BW,C2$\rangle$, which confirmed the significant difference in their proportions ($p = 0.013$ in both cases). In the bottom portion of Figure 5, we note that the proportion of preferences for the base symbol, which was present in all tests, was significantly lower than the proportions of the other adaptations ($p \ll 0.001$), which reinforces the support for the hypothesis central to this research.

Analysis of the *number of symbols counted* in each test was done for the major types of adaptations. This was because all minor variants of each adaptation were always tested simultaneously (see Table 1), thus making it impossible to drill down to that level of detail.

Figure 6 shows box-plots of symbols counted for all adaptation types, plus an MX (mixed) pseudoadaptation that represents the scenario in which participants were exposed to all adaptations, corresponding to the two tests in block E. The median number of symbols counted ranged from 11 to 13, out of a maximum of 13. Some participants reported more than the actual number of symbols on the computer screen, but we decided not to discard data because that happened irrespectively of the adaptation type.

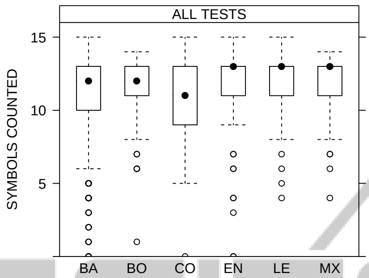

Figure 6: Symbols counted by major type of adaptation.

To check if symbol counts differed between pairs of adaptations, we first applied a Shapiro-Wilk test, which revealed that the normality assumption could not be accepted for any of the data distributions ($p \ll 0.001$). Next, we applied a two-sample Wilcoxon test to all 15 pairs of adaptation types, and adopted an α value of 0.003 to control for family-wise errors.

Results revealed that participants counted less symbols when exposed to the CO adaptation than in the LE and MX conditions ($p < 0.001$). Thus, even though Figure 6 suggest higher symbol counts in the EN, LE, and MX conditions, none of the adaptations differed significantly from all the others.

Figure 7 shows box-plots of symbol counts in the light and dark background conditions, with medians 13 and 11, respectively, a difference considered significant by a two-sample Wilcoxon test ($p \ll 0.001$).

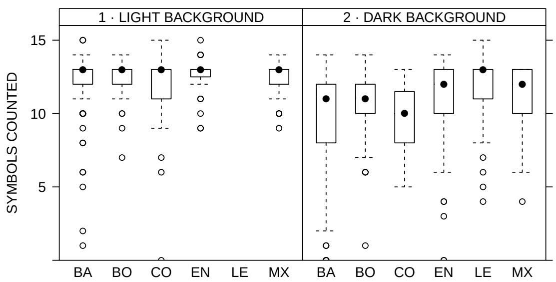

Figure 7: Symbols counted by adaptation, per background.

Comparing each adaptation individually in the two background conditions lead to similar outcomes ($p \ll 0.001$), differing only in the median values. This suggests participants may have had more difficulty in finding symbols when the dominant luminosity of the background photo was dark.

5 DISCUSSION

The results from the user study revealed two main findings: firstly, the proposed symbol adaptations were preferable to base symbols in scenarios representative of AR conditions which benefited from improved symbol salience; and secondly, adding a border and adjusting the colour luminosity of symbols were the most popular adaptations. In this section, we examine the validity of the strategy behind this research, discuss the preservation of symbol semantics and how we intend to address it more properly in future work, and, finally, argue about the applicability of our findings to AR development.

We evaluated different adaptations using an empirical user study in controlled settings. Thus, we choose a *research strategy* that minimises external influences to keep the results precise and comparable, at the expense of realism and generalisability (McGrath, 1995).

Indeed, one limitation is that all tests were conducted indoors, whereas users of mobile AR applications will likely be outdoors. In this regard, we tried to increase realism in two ways: firstly, by using photos of urban landscapes as background images, so that potential effects specific to the overlay of symbols against common objects such as trees and buildings would be captured in the study; and secondly, we considered photos with shadows and poor illumination as well as photos shot under bright sunlight, to simulate two natural settings. Other studies in the literature were also performed indoors, for instance using posters with high-resolution photos (Gabbard et al., 2007). Another limitation is that the symbols tested were restricted to a simple, yet popular, rectangular shape. We did not explore other symbol designs, such as the cartoon-like symbols of the Canadian emergency mapping symbology (GeoConnections, 2010), to simplify the study. More work is necessary to increase realism, and our ongoing studies are being carried out outdoors and we replaced the laptop for a mobile hand-held device.

Concerning the generalisability of the results to a variety of populations, one of our goals was to find participants from both genres covering a wide range of ages. In this regard, the convenience sample used was effective in contacting 55 volunteers, with a 40/60 proportion of men and women, from 20 up to 79 years of age. Nevertheless, we identify two limitations: firstly, we have not analysed results by age bands, the major reason being that we did not find a commonly accepted approach for this, even though additional outcomes could arise; and secondly, we do not have data for people below 20 years of age, who will likely play an increasingly important role in the consumer market, for instance, as players of mobile AR games (Wetzel et al., 2008). Future work is needed to address these limitations, and we note it may be difficult to obtain parents' permission to contact young participants.

This research was conducted having in mind the *preservation of symbol semantics*. In a way, this is a case of not only 'respecting' the real world images, as per the definition of AR in Azuma (1997), but also 'respecting' the virtual symbols that are overlaid, providing supplementary data that needs to be correctly interpreted by the user. In fact, we did not evaluate semantics, but have made informed efforts to preserve it. Thus, the colours chosen in some adaptations were neutral, we adjusted luminosity (not hue or saturation, which could turn green into red, for instance), and the increase in symbol size was moderate.

Given the results from this study, in our ongoing work we are asking users to subjectively evaluate symbol semantics. In addition, we are investigating preferences regarding adapting only the symbols that might be confused with the background versus having all symbols equally adapted for the entire real world image, which could make the symbols (as a group) more conspicuous and could minimise questions about why supposedly equivalent symbols look different.

Finally, regarding the *applicability in AR*, this work concerns video see-through AR systems, as it requires image analysis. Actually, this is not a limitation because these systems are currently available on mobile phones, allowing a growing number of users to experience AR. This fosters the development of a wide range of AR applications, such as the visualisation of points of interest and scientific data, that could benefit from the proposed symbol adaptations.

6 CONCLUSIONS

The problem addressed in this paper is that in AR applications it may be difficult to discern virtual symbols from the surrounding background image if their colours are similar. Therefore, we proposed a set of adaptations to make virtual symbols more salient from the background, while preserving the original semantics. We conducted a study to empirically evaluate the adaptations, which revealed that adding a border and adjusting the colour luminosity were the two favourite adaptations in scenarios in which symbols had colours purposefully similar to the surrounding image.

Ongoing work explores the use of these two favourite adaptations on AR applications for mobile devices in outdoor environments. We are testing if these adaptations preserve symbol semantics, and also analysing the minimum variation in luminosity that makes a symbol distinguishable in both light and dark backgrounds. Further research could consider, for instance, new adaptations and other types of symbols.

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