Symbol Adaptation Assessment in Outdoor Augmented Reality

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Abstract: A challenge in presenting augmented reality information, particularly in outdoor environments, is to distinguish the virtual symbols from the background image. In this paper we report on a user study that leverages prior knowledge about adaptations to improve symbol conspicuity by expanding its application to outdoor environments and mobile handheld devices. We considered two types of adaptation that yielded good results indoors, namely adding a border around the symbol and adjusting the colour luminosity, and tested them outdoor in daylight. We also introduced partial and total adaptation modes that differed in the scope of the symbols to adapt: only the ones that are almost imperceptible from the background versus every symbol overlaying the real world image. Results from users' questionnaires reveal that the border adaptation continues to be the favourite regardless of the outdoor lighting conditions, and yet we did not find differences in symbol detection performance in comparison with adjusting colour luminosity. The border adaptation was also considered the best to preserve symbol semantics when combined with the total adaptation mode, thus making it a versatile option for augmented reality applications.

1 INTRODUCTION

Augmented Reality (AR) applications superimpose virtual graphical representations on images captured from the real world to provide additional information to the user. Nowadays this technology can be used in smartphones and tablets, which has led to an increasing interest in its use. But the virtual symbols may not be easily detected on the image when their colour is similar to the background colour. This is even more severe in outdoor AR, where there is no control over the environment and lighting conditions vary widely (Gabbard et al., 2007).

Dynamically adapting the graphical attributes of symbols when they become indistinguishable from the background image can improve their visualization, but drastic changes in the symbols' appearance may confuse the user. Consequently, the adaptations should make symbols more salient while preserving the original semantics associated with them.

Another example of the pertinence of this problem is the visualisation of scientific data in AR applications, for instance colour-encoded pollution levels in urban landscapes (White and Feiner, 2009), which also requires dynamic adaptations that maintain the semantics of the graphical representations to support correct and consistent interpretations of the data.

The goal of our research is to investigate how to adapt symbols automatically in order to improve their distinctiveness from the background images, preserving the original semantics and without moving them to new positions.

In a previous work (Carmo et al., 2013) we studied a set of adaptations that make controlled adjustments to the colour or size of the symbols, or change the colour of the letters or digits inside the symbol, or add a border around them. We assessed user preferences in scenarios where the symbols were purposefully very similar to the background image and the results revealed that adding a border and adjusting colour luminosity were the preferred symbol adaptations. However, we did not evaluate if the adaptations maintained the semantics of the symbols. Moreover, the study was carried out indoors and using a laptop.

Since outdoor environments are more demanding than indoor settings, in this paper we focused on the two favourite adaptations and studied their use in AR outdoor applications with mobile devices. Furthermore, we assessed if symbols maintained their semantics considering two separate modes of adaptation: adapting only the symbols that might be imperceptible from the background versus adapting every symbol in the image.

The results obtained are organized as follows: section 2 describes the related work; section 3 explains the symbol adaptations that we tested; section 4 describes a user study for evaluating users' preferences as well as the efficiency and effectiveness in symbol selection tasks; sections 5 and 6, respectively, present and discuss the results; and finally, in section 7 we draw conclusions and point out future work.

2 RELATED WORK

One of the major challenges documented in the AR literature is how to provide users with additional information about the real world as it evolves. Kalkofen et al., (2009) proposed several techniques to support the combination of virtual objects and real world images, and suggested 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 harmonised based upon aesthetics guidelines. Since the colour of some real world objects may be important for their meaning, while with others that may not happen, the objects were classified accordingly, thus restricting or allowing colour manipulations by the AR application.

In this paper, we also make adjustments to the colours of virtual symbols, but leave real world images untouched, following a classical trend in AR (Azuma, 1997). Furthermore, in one of the adaptations presented in the next section, we focus on enhancing symbol conspicuity by controlling mainly the luminosity component of colour, that is, we induce symbols to be perceived by the user as being slightly more or less bright, rather than, say, turning black into red, which could more likely alter symbol semantics (Silva et al., 2011).

Thomas et al. (2000) studied what should be the adequate colours to draw monsters in the ARQuake game, an outdoor/indoor mobile AR application. The authors conducted an informal experiment to determine the best colours for specific outdoor settings, using nine different colours with four levels of intensity in each setting. The results showed that there is a set of appropriate colours/intensities for each outdoor setting. The goal of that study was to recommend a set of colours for a specific setting; however, our work aims to study symbol adaptations to make them more salient in any outdoor setting.

Besides graphical symbols, text can be used to provide additional information in AR applications. Gabbard et al., (2007) analysed the influence of outdoor lighting conditions in text readability and tested algorithms to improve text contrast relative to the background image, for instance by outlining the letters. This feature relates with the need that graphical symbols should be perceived as units of information, preferably forming closed figures and having well-defined boundaries (Sanders and Mc-Cormick, 1992, pages 122–123). For instance, Nivala and Sarjakoski (2007), regarding the adaptation of graphical symbols for maps on mobile devices, suggested adding a border around points of interest. Naturally, maps are different from real world images, but nevertheless the same problem of symbols being confounded with the background exists.

Another study of text readability was carried out by Leykin and Tuceryan (2004), who did experiments with users to create pattern recognition models to automatically 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 which allowed higher readability. Our work aims to adapt graphical symbols so they become distinguishable from the real world image, without moving them to new positions.

Wolfe and Horowitz (2004) analysed the attributes that guide visual search and concluded that colour, motion, orientation, and size are the most important. Almost the same attributes were studied by Paley (2003) to distinguish the text in a transparent, overlay, window from the background text.

Taking into account these studies, and guided by the need to preserve symbol semantics and avoid modifying real world images, we proposed, in a previous work (Carmo et al., 2013), a set of adaptations for AR applications and performed a study to evaluate users' preferences to improve symbol conspicuity in a controlled indoor environment and with a laptop. In this paper we leverage the knowledge about the users' preferred adaptations by expanding its application to an outdoor environment and mobile handheld devices, and by evaluating semantics preservation, as described in the next section.

3 ADAPTATION OF SYMBOLS

The aim of our study is to identify good adaptation approaches to make virtual symbols more salient from the background in AR applications when the colour of the surrounding image and the virtual symbols are similar. These adaptations have to be thoroughly chosen to ensure that the semantics of the original symbols is preserved.

In previous work, we considered four major types of adaptation (Carmo et al., 2013):

- Adding a border around the symbol: white and black borders were considered to avoid misleading interpretations that could be introduced by the use of colours (Figure 1b and c, respectively).
- Adjusting the colour luminosity: symbols are drawn slightly lighter when the background is dark (Figure 1d), and a bit darker when the background is light.
- Enlarging the symbol: a factor of 1.5 relative to the size of the base symbol was used (Figure 1e).
- Changing the colour of the letters or digits inside the symbol: the characters on the symbol were depicted in white when both the background and the symbol had a dark colour (Figure 1f).

The base symbol (Figure 1a) is adapted whenever the dominant colour (the colour having the highest frequency) of the symbol and the dominant colour of a rectangular image region that encloses the symbol are considered similar. This happens when the absolute difference between each of the three RGB colour components is less than a threshold.

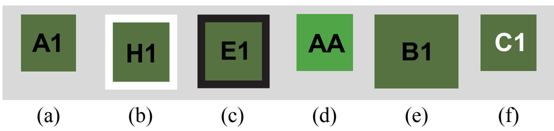

Figure 1: Examples of base and adapted symbols.

The results from a user study revealed that adding a border was favoured by the majority of the participants followed by adjusting the colour luminosity. Although we chose a neutral colour to the symbol border and adjusted only the luminosity (not hue or saturation) to preserve the semantics of the symbols, we did not assess if the adaptations achieved our goal. Furthermore, the study was conducted indoors and using a laptop.

These two limitations were the motivation for the work presented in this paper. As a starting point we used the two favourite adaptations of our previous work, then we proceeded our work on adaptation of symbols considering their use for AR outdoor applications in mobile devices. In addition, we addressed the study of semantics preservation by considering two separate modes of adaptation: adapting only the symbols that might be imperceptible from the background versus adapting every symbol in the image. That is, we wanted to assess if the adaptation of only some of the symbols could confuse the observer, raising the question of why supposedly equivalent symbols look different.

Adjusting the Luminosity. As stated before, to preserve symbol semantics it is essential to ensure that there is no abrupt change of their original colour, which is why we adjust only the luminosity of the symbols. For this purpose, we used the HSV model, which represents colour according to the three components hue, saturation and value, because it allows direct control of the luminosity through the value component. This model is preferred for image enhancement applications due to its separation of the chrominance and luminance values (Asmare et al., 2009).

We conducted a preliminary study to identify the minimum variation in luminosity that makes a symbol distinguishable with both light and dark background images, particularly outdoors in a sunny day (Montez, 2012). In fact, in AR applications used outdoors it is difficult to control lighting conditions, which can vary from 1 lux to 100,000 lux (Gabbard et al., 2006).

Considering situations in which the colour of the symbol is similar to the colour of the background, the results of the study revealed that it should be considered a difference of 0.25, in the range [0,1], in their value' s components. This is the minimum difference to ensure the user distinguishes the symbols from the background, regardless of the background colour being light or dark.

Mode and Type of Adaptation. As mentioned before, we considered two *adaptation modes*: adapt only the symbols that are imperceptible (PA - partial adaptation) or adapt all the symbols (TO - total adaptation). In the latter mode we considered two cases: firstly, after the adaptation all the symbols remain perceptible (TA - total all adaptation); and secondly, some of them that were originally perceptible become undistinguishable from the background after the adaptation (TS - total some adaptation).

The *adaptation type* corresponds to adapting the base symbol (BA) by adding a border (BO) or adjusting the colour luminosity (CO). Adding a border means that we add a white or a black border to symbols depending on the type of the background image being dark or light, respectively.

The base symbol is a square of 40x40 pixels and the border is a line with a width of 3 pixels, as recommended by Huang and Chiu (2007).

The adaptation that adjusts the colour works by increasing or decreasing the luminosity of colour by 0.25 in the range [0,1], as described above. It is increased if the luminosity of the dominant colour of the background of the symbol is less than or equal to

0.5, and reduced otherwise. A special case is when the colour luminosity of a symbol is less than 0.1, because in these circumstances it is perceived as black when outdoors (Romani, 2012). To avoid that a symbol that seems black become coloured, we adjust the symbol in a gray scale, that is, the saturation is set to 0 and the luminosity is set to 0.35, obtained by adding 0.25 to 0.1.

4 USER STUDY

The user study is organized in three parts. The main objective of part 1 is to analyze the users' preferences on the adaptation mode per type of adaptation. Part 2 compares the efficiency and the effectiveness of each adaptation type and in part 3 we want to know the users' preferred adaptation type.

Considering these specific purposes our main hypotheses are:

H1: Participants prefer the adaptation of all symbols (total adaptation mode) to preserve semantics when considering the type of adaptation *adding a border*. This hypothesis is based upon the Gestalt similarity principle, which claims that elements tend to be integrated into groups if they are similar to each other (Dix et al., 2004). Thus, if all the symbols are equally adapted they should be equally interpreted semantically.

H2: Participants prefer the partial adaptation mode to preserve semantics, when considering the type of adaptation *adjusting the colour luminosity*. As mentioned before, this adaptation type only manipulates the luminosity component of the colour to enhance the contrast of the symbols with the background and avoid affecting its semantics. Therefore, when adjusting only the symbols that might be imperceptible there should be no significant change of semantics, because colour perception depends on the surrounding context (Stone, 2005). Also, the application of the same adaptation to all symbols (corresponding to the total mode) could lead to a degradation of the visibility of some of the symbols that were originally perceptible.

H3: Participants are faster (efficiency) and more accurate (effectiveness) in carrying out symbol selection tasks when considering the type of adaptation *adding a border*. This hypothesis is motivated by the results obtained in our previous study that showed the majority of the participants preferred this type of adaptation in a similar type of task.

H4: Participants prefer adding a border as the best adaptation to improve the detection of symbols. This hypothesis is also based upon the results obtained in our previous study, which was conducted indoors with a laptop.

Participants. A total of 22 participants, 14 men and 8 women, volunteered to the study. The median age was 28 years, with 14 participants aged between 15 and 24 years, 4 from 25 to 39 years old, and the remaining 4 had between 40 and 53 years. 5 were undergraduates, 10 participants were graduated, and 7 had a master or a PhD degree.

A self-assessment of mobile device and AR experience revealed that 15 participants used mobile devices daily, 3 weekly, 1 rarely and 3 of them had never used a mobile device. Some of the participants had at least one previous experience with AR applications, 6 weekly, 5 rarely, but 11 were not even aware of the concept.

A convenience sampling was used to select the participants, who were recruited from social contacts. No monetary reward was offered.

Apparatus. The tests were performed outdoors in sunny days, in the shadow, but near a sunlit area and with illuminance values that ranged from 2500 lux and 13000 lux, with an average of 6070 lux. The illuminance was measured with a light meter Model YF Yu Fung - 1065. These values are in the range suggested by Gabbard (2006), from 2000 lux to 25000 lux, which represents the limits in outdoor environments. This means that it was possible to evaluate the adaptations using normal external conditions and very similar for all participants.

The tests were conducted in June and July, between noon and 8pm.

We developed and used a Java application with a SDK for Android API 8 for the user study. This application is composed of a training part and the tasks that comprise the study. The study was carried out with a LG P500 smartphone, running Android OS 2.2, featuring a 600 MHz processor and a 3.2 inch touch screen with 320x480 of resolution. The luminosity of the device was set to 35%.

Tasks. Participants were asked to perform *selection* and *preference* tasks. In each test, an image with superimposed symbols was shown to the participant and to ensure that s/he identified all of them s/he should touch all the symbols in the image. The preference task immediately followed the selection task. The participant answered verbally to questions about the mode and type of adaptation and the researcher wrote down the answer.

Part 1 of the study concerns the preferences about the mode of adaptation (TO and PA) to evaluate which was preferred and if these adaptations

(a) (b) (c)

Figure 2: Example of the first part of the study - Sequence of images of test T1.

maintain symbol semantics. A participant was exposed to one adaptation mode at a time and was asked if s/he considered that semantics was preserved. After been exposed to a total mode and partial mode s/he was asked which of them was the preferred.

Part 2 regards the efficiency and effectiveness with each type of adaptation (BO and CO). The participant was exposed to one adaptation type at a time. We measured and compared the efficiency and effectiveness with each type of adaptation by counting the number of tapped symbols and registering the time it took to perform the task.

Part 3 of the study refers to the preferences about the type of adaptation (BO and CO). The participant was exposed simultaneously to both adaptation types and, in the end, said which was preferred.

Design. 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.

In part 1, we manipulated three independent variables, namely, background, type of adaptation BA, BO and CO, and mode of adaptation, TO and PA. Notice that the TO mode of adaptation includes two cases, TA and TS, as mentioned before. The dependable variable was the preferred mode of adaptation (total or partial).

Regarding the background variable, we distinguished between dark and light images over which the symbols were placed. We used two sets with 3 images each, representative of natural scenes with shadows or poor illumination (dark background) and bright sunlight (light background), respectively.

For the virtual symbol we considered a square with a colour similar to the dominant colour of the background and containing a fork and a knife (a popular representation of restaurants) whose colour had a low contrast with the symbol's colour. This aimed to make the symbol not easily detected by its content in order to study whether the adaptations were effective. All symbols displayed were equal and, purposely, only some of them were difficult to distinguish from the background (Figure 2a).

In each test, a background image was presented three times to the participant and the position of the symbols did not vary (Figure 2b and c). In the first case, the symbols were shown with no adaptation (BA); then, with one of the adaptations mode, either a total (TA or TS) or a partial adaptation (PA); and finally with the other mode (partial or total).

The manipulations of the type of adaptation and background were organized in 6 tests according to Table 1.

Table 1: Tests in part 1 of the study.

#	Adaptation Type	Adaptation Mode	Background
T1	BA, BO	TA, PA	light
T2	BA, BO	TA, PA	dark
T3	BA, CO	TA, PA	light
T4	BA, CO	TA, PA	dark
T5	BA, CO	TS, PA	light
T6	BA, CO	TS, PA	dark

The pairs of tests (T3, T4) and (T5, T6), each one with a light and a dark background, deal with colour adaptation, but illustrate different approaches. With the first pair, we a have a TA case, in which all adapted symbols are distinguishable from the background. But with the second pair, we have a TS case, where some of the symbols become undistinguishable after being adapted, even though they were original salient from the background. For the border adaptation, we only have a pair of tests (T1, T2) corresponding to the TA case, as we cannot consider the TS case: if a symbol is salient, even if we add a border similar to the background, the symbol will continue to be salient.

In part 2, we manipulated two independent variables: background and type of adaptation (BA, CO, and BO). The dependable variables were the number of selected symbols and the time to select all symbols in the image. The symbols were adapted with the total mode. The tests were organized according to Table 2.

Regarding the background variable, we considered two images: a dark image and a light image with the same illumination requirements as in the first part.

Table 2: Tests in part 2 of the study.

#	Adaptation Type	Background
T7	BA, CO	dark
T8	BA, CO	light
T9	BA, BO	light
T10	BA, BO	dark

We used square symbols filled with a uniform colour similar to the dominant colour of their surrounding background, making the symbols hard to find. The goal was to measure how many symbols were found and how long it took to find the symbols with and without adaptations. In each test the background image was presented twice to the participant: first, it was displayed with only base symbols; then, with all symbols adapted (Figure 3). The location of the symbols was different in successive images to avoid learning effects. The same light and dark backgrounds were used for both adaptation types.

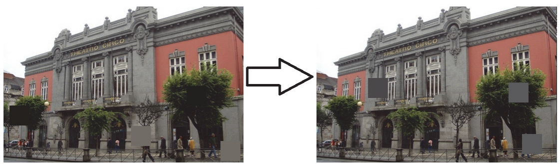

Figure 3: Example of Part 2 – Sequence of images of T7.

In part 3, we considered three independent variables: background, type of adaptation (BA, CO+BO) and symbol content (PL - plain symbol, LE – symbol with a letter). The symbols were adapted with the total mode. The dependent variable was the preferred adaptation type (border or colour). Light and dark backgrounds were considered as in the preceding parts of the study.

In each test, the background image was presented twice. In the first case, the symbols were not adapted and were located in places where they were not salient. Then all of them were adapted, some with the border adaptation and the remaining with the colour adaptation. The location of the symbols was different in successive images to avoid learning effects.

We considered two types of symbols: square symbols filled with a uniform colour similar to the dominant colour of the surrounding background, like those in part 2; and symbols containing a letter in the center ("H") to give them semantics and assess if the participant's answer was different. Table 3 presents the list of tests and the respective independent variables values.

Table 3: Tests in part 3 of the study.

#	Adaptation Type	Symbol Content	Background
T11	BA, CO+BO	PL	dark
T12	BA, CO+BO	PL	light
T13	BA, CO+BO	LE	light
T14	BA, CO+BO	LE	dark

Procedure. A trial started when a participant received the mobile device in an outdoor location. The researcher annotated the test conditions, namely, location, date and time and the illuminance values in lux. Then, an introduction to the nature of this experiment was given, along with an estimation of the time that the trial would take: between 20 and 30 minutes. Next, the researcher filled out a demographic questionnaire (age, gender, academic degree) according to the answers given by the participant, which also contained questions about the degree of familiarity with mobile devices and augmented reality applications. Then, the researcher described the type and modes of adaptation and the tasks to be performed in each part of the study.

After this introductory phase, participants were presented with training tasks to let them familiarize with the application and clarify any doubts concerning the tasks. Hereafter, participants carried out 14 experimental tests, organized in three sequential parts, as mentioned earlier. To start each part of the study, participants were required to tap on a "Start" button displayed on the screen. In each part, to proceed to the following task, the participant tapped in a "Next task" button. Each task ended when participants tapped on the last symbol presented. If a participant did not select any symbol s/he received a message asking if s/he really wanted to proceed.

We created eight versions of the tests to control the order of the presentation of experimental conditions. In part 1, in half of the test versions, the participant began with an adaptation adding a border and in the other half, with an adaptation adjusting the colour. The mode of adaptation presented to the participant was also controlled creating half of the versions starting with images with a total adaptation (TA or TS) and half with partial (PA). In part 2 we created four versions to control the order of exposure of the adaptation mode and for each one the order of the background type. In part 3, there were also four versions, controlling the order of the exposure of symbol content and type of background.

5 RESULTS

Results are organized in 3 parts: firstly, we evaluate partial versus total adaptation modes; secondly, we compare the efficiency and the effectiveness of adding a border and adjusting colour luminosity adaptation types; finally, we access the preferences of the participants by adaptation type.

Partial versus Total Adaptation Modes. The opinion of the participants about the preservation of semantics by adaptation mode is presented in Figure 4 for adaptation types BO and CO, respectively. The TA adaptation mode obtained the best results for the BO adaptation type and a test of equal proportions showed that the differences to the PA mode are significant (X^2=7.31, 1 df, p<0.007). This result supports hypothesis H1. However, when the adaptation type is CO, the TS adaptation mode received more favourable opinions about semantics preservation, which is contrary to hypothesis H2. A two-sample test for equality of proportions, with Bonferroni correction, revealed that the differences between TS and PA (X^2=9.74, 1 df, p<0.002) and TS and TA (X^2=6.03, 1 df, p<0.0015) were significant.

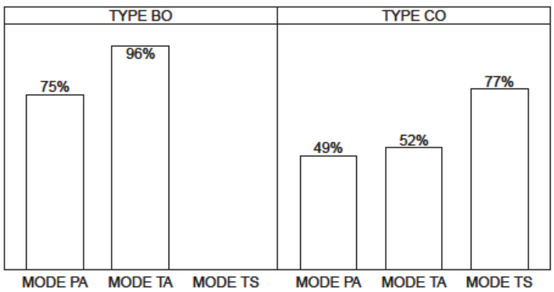

Figure 4: Positive opinions about preservation of symbol semantics by type and mode of adaptation.

There were no significant differences in the results considering genre, background (light or dark), background image, and the order of the tests (p>0.07 in all tests of equality of proportions). Regarding the luminosity, there were no interferences for the BO adaptation type (p=0.07), while for the CO adaptation type luminosity influenced the results of the PA adaptation mode (X^2=8.56, 3 df, p=0.04).

In the question about the preferred mode of adaptation, we combined all the answers corresponding to the total adaptation mode in the CO adaptation type (TO=TA+TS), as both represent an opposite choice to the PA mode. For the BO adaptation type, TO has the same meaning of TA. Results show that participants preferred the TO mode for both adaptation types (Figure 5). For type BO, a test of equality of proportions for the pair (TO, PA) confirmed significant differences (X^2=35.64, 1 df, p<<0.001), which again supports hypothesis H1. However, for the pair (TO, PA) in the CO mode, the test of equal proportions reveals that hypothesis H2 should be rejected, as there is no significant difference in the adaptation mode's preferences (X^2=1.46, 1 df, p>0.22).

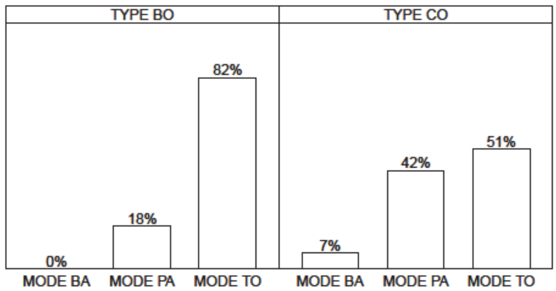

Figure 5: Preferred adaptation mode by type of adaptation.

The preference results for the BO adaptation type did not have significant differences considering the background image, the type of the background image, the order of the tests, and the luminosity (p>0.12), but were influenced by genre (X^2=5.59, 1 df, p=0.02). The results for the CO adaptation type also did not depend on the luminosity (p>0.80) and on the order of the images (p>0.24), but reveal influences from the background image (X^2>10.69, 3 df, p<0.01), background (X^2>3.78, 1 df, p<0.05), and genre (X^2=4.22, 1 df, p=0.04).

Symbol Selection Performance. The number of symbols selected by participants was frequently equal to the 3 available symbols. Thus, the data distributions, regardless of the adaptation type, were not normal as revealed by a Shapiro-Wilk test (W<0.74, p<<0.001). The box-plot in Figure 6a suggests that several data points were below the maximum for the BA condition, and indeed, by applying two-sample Wilcoxon tests, we found significant differences in the overall counts between BA and the other two types of adaptation (W<1113.5, p<<0.001).

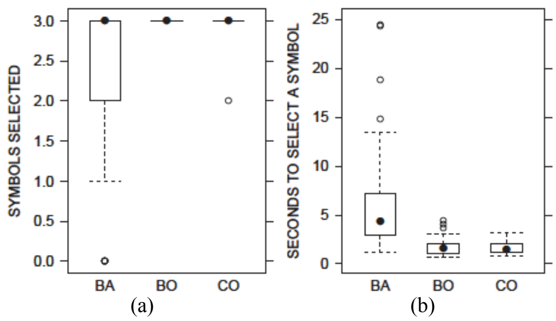

Figure 6: Effectiveness and efficiency of symbol selection per adaptation type.

However, a difference could not be accepted between the BO and CO conditions (p=0.32), and, in spite of our efforts, the results suffered from interferences by variables such as genre, background, outdoor illuminance, and others. Thus, we find no ground to accept hypothesis H3 regarding the number of symbols selected.

The other element of symbol selection in H3 is the average time to select a symbol, which was on average 5 seconds (median 2.7) greater in the BA condition, as shown in Figure 6b. A Shapiro-Wilk test showed the data distributions were not normal ($W<0.93$, $p<0.012$), so we applied two-sample Wilcoxon tests that revealed the difference was significant ($W<3397.5$, $p<0.001$).

However, symbol selection efficiency was mostly the same in the BO and CO conditions (Wilcoxon test, p=0.58). Thus, we cannot find evidence to support hypothesis H3.

Preferred Adaptation Type. In this part of the paper we wanted to complement the results obtained in our prior work (Carmo et al., 2013) by evaluating the preferred type of symbol adaptation in an outdoor environment, rather than indoors, and using a mobile handheld device, instead of a laptop.

Actually, the results reinforce the previous evidence: adding a border to symbols (BO) continued to be preferred by the majority of participants with 96% versus 91% from our earlier study. The remaining 4% corresponded to the other adaptation type participants were simultaneously exposed to, which was adjusting the colour luminosity (CO). A test of equality of proportions naturally revealed a significant difference (X^2=145.45, 1 df, $p<<0.001$).

Furthermore, Figure 7 shows a complete dominance of the BO adaptation with dark background images, regardless of the outdoor lighting conditions that we recorded during the experiment.

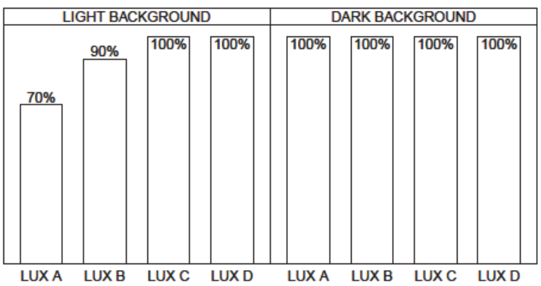

Figure 7: Proportion of BO preferences per background and outdoor lighting. The illuminance scale (LUX A, B, C, D) ranges in equal parts from 2500 up to 13000 lux.

The choice of the preferred adaptation type was not affected by genre, images of the real world, and order of exposure to the tests (p>0.24). However, with light backgrounds, the outdoor lighting probably influenced the proportion of participants choosing the BO adaptation (X^2=7.7, 3 df, p=0.05). Nonetheless, the absolute value of those proportions was always very high (>=70%).

In these circumstances, we can accept hypothesis H4 stating that adding a border around symbols is the preferred adaptation.

6 DISCUSSION

One of the goals of this work was to increase realism and generalizability when compared with our previous study (Carmo et al., 2013). Some limitations pointed out were that the tests had been conducted indoors with a laptop computer, as well as the simplicity of the symbols used.

So, although the experiment described here must have similarities with the previous one, such as the adaptation types, and the light/dark background images, we addressed the realism limitation in two ways: firstly, all tests were carried out outdoors with a mobile handheld device, reproducing a plausible activity of consumers; and secondly, we enhanced symbol semantics by choosing symbols identical to those used in the representation of points of interests, such as the fork and knife of restaurants. Nevertheless, additional work is necessary to explore more complex symbol designs, as we continue to have square symbols.

For the sake of precision and comparability, we set the luminosity of the handheld device to 35% and all the participants were exposed exactly to the same images.

Concerning the generalizability of the results to a variety of populations, we tried to find participants covering a wide range of ages, both genres and with different experiences in using mobile devices. In further studies we intend to cover a wider range of participants.

Regarding semantics preservation we verified that when adding a border the preferred adaptation mode is total adaptation (hypothesis H1).

However hypothesis H2 was refuted: when exposed to symbols with adjusted colour luminosities, participants did not prefer the partial adaptation mode. Colour perception depends on both the colour of the symbol and the colour of the surrounding background, that is, it is contextual. Therefore, it could be expected that only the symbols that are not distinguishable from the background needed to have an adjustment in luminosity. Nonetheless, the total mode adaptation was the preferred one. This may be due to the influence of some variables, especially, luminosity.

Further research is needed to improve the colour adjustment algorithm. A limitation of the present algorithm is that it darkens the symbol when the value component of HSV is above 50%. This threshold should be increased to preferentially lighten the symbol. Another enhancement is to consider the second dominant color of the surrounding background to detect similarities between the symbol and the background.

Another extension to this study is to consider different lighting conditions, using a broader range of illuminance values, including, for instance, direct sun light exposure in a bright sunny day.

Taking into account the preferences expressed in our previous study, we expected that the selection of the symbols would be performed faster and more accurately when considering adding a border adaptation than adjusting colour luminosity (hypothesis H3). Actually, the results do not show significant differences, as they were influenced by some of the controlled variables. We also admit that there were few symbols to be detected due to the limited size of the screen. The experiment could probably be improved by exposing participants to a larger number of symbols over periods of time, instead of considering s fixed number of symbols superimposing a static background image.

This study reinforced the results obtained in our prior work in that adding a border is preferred over adjusting the colour luminosity (hypothesis H4) regardless of the outdoor luminosity conditions.

7 CONCLUSIONS

Given the results from our previous study, leading to the conclusion that the two favourite adaptations were adding a border and adjusting the colour luminosity, our goal in this paper was to evaluate if these adaptations maintained symbol's semantics.

We investigated preferences regarding two alternative modes: adapting only the symbols that might be imperceptible from the background versus adapting every symbol in the image. That is, we assessed if the adaptation of only some of the symbols could confuse the observer, raising the question of why supposedly equivalent symbols look different. The user study was performed outdoors with a mobile handheld device in conditions close to real use.

The main findings of our study were: we confirmed the result obtained in our previous work that adding a border is preferred over adjusting the colour luminosity regardless of the outdoor luminosity conditions; we concluded that with border adaptation all symbols should be adapted to preserve semantics; and we identified also the same tendency when colour luminosity adaptation was used.

Ongoing work explores these approaches in AR scientific data visualization, which is particularly demanding regarding semantics preservation, using a tablet instead of a smartphone. Further research is needed concerning other types of symbols and adaptations, and a broader range of lighting conditions.

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