Automatic Projection Positioning based on Surface Suitability

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ABSTRACT
Projectors most likely will be embedded into the next generation of mobile devices, and thus projecting pictures and videos into the physical world will be an important use case. However, the projection positioning in the real world is challenged by surface reflections or objects in the environment. As adjusting the projected image manually is cumbersome, in this work, we introduce a camera-based algorithm to measure the projection suitability of arbitrary surfaces by using three classifiers that can be derived automatically and in real-time from a camera image. Through a user study, in that participants rated the projection quality of different surfaces, we developed guidelines to indicate suitable projection spots using the three classifiers. As a proof of concept, we implemented a mobile prototype applying the proposed guidelines. This prototype automatically scales and places projected content at the position in everyday environments that promises the best projection quality.

ACM Classification Keywords
H.5.2 Information interfaces and presentation (e.g., HCI): User Interfaces.

Author Keywords
Projector Phones, Adaptive UI, Camera-Projector System

INTRODUCTION AND BACKGROUND
Nowadays mobile devices are ubiquitous devices that contain advanced technology, such as cameras. Through the proliferation of digital cameras and cameras built into phones, more and more digital content is being produced. Hence, persons often find themselves in a situation where a digital picture or video has to be shared but the screen space is just too limited. Especially when showing digital content to several persons, the limited screen space results in a bad viewing experience for the viewers (see Figure 1). To solve this problem, Schöning et al. [16] suggested to extend mobile phones

PerDis '16, June 20–22, 2016, Oulu, Finland.

DOI: http://dx.doi.org/10.1145/2914920.2915014

Figure 1. A group of people is simultaneously trying to look at a picture which causes a bad viewing experience.

with projectors. Such phones can project digital content into the physical world and extend their screen space. Projector phones are already commercially available e.g. the Galaxy Beam[1] .

Projecting content into the physical world has been addressed by various research projects. Pinhanez [14] proposed to augment physical objects with digital content. As distortion is a problem, it was suggested to correct the projection using a camera to enable a distortion free projection on objects in the physical world. Further Büttner et al. [4] and Funk et al.[7] are using this concept to provide projection-based cognitive support during assembly processes. Butz et al. [5] use projection to highlight a sought book in a shelf, and Löchtefeld et al. [13] use projection to augment shopping experiences. Further Funk et al. [8] are suggesting to use mobile projection for order picking tasks. Beardsley et al. [2] uses a mobile camera-projector system to align the projection based on unique points. They suggest using defined spots for projecting content, which stay at their defined place even when moving the projector. The movement of the projector can then be used to interact with the projected content using a digital cursor. Especially for interacting with mobile projectors, many areas of applications have been suggested. Rukzio et

[1]http://www.samsung.com/hk_en/support/model/GT-I8530BAATGY (last access 04-19-2016)

al. [15] provide an overview about mobile projection. Despite the already mentioned interaction through moving the projector, the user can also directly interact with projected content. Thereby, a camera is tracking defined interactive areas of projected content and triggers actions when the area is triggered. This is done by Wilson [17] using a stationary setup for creating an interactive projection, while Harrison et al. [10] use a mobile setup. Moreover, Gugenheimer et al. [9] use this concept for a domestic deployment of interactive projection.

With mobile projection, the need for correcting the projection increased. Bimber et al. [3] suggest an algorithm that first scans the surface and then corrects the projection to eliminate distortion of the projected image caused by the color of the surface. However, especially with very dark or reflecting surfaces this is not always possible. Sometimes, it might just be enough to place the projection at a suitable position, where the projection quality is not decreased by sub-optimal surface colors and reflections.

In our work, we propose guidelines for calculating a value of perceived projection suitability that is based on three parameters that can automatically be detected. The contribution of this paper is two-fold. (1) Based on a user study, we propose guidelines to calculate perceived projection area suitability. (2) As a proof of concept, we introduce an algorithm using the proposed guidelines for identifying such projection areas.

ASSESSING PROJECTION SUITABILITY

We define projection suitability (PS) as a property of a surface indicating the perceived quality of a projection on that surface. For assessing the PS of a surface, we consider three properties of a surface's image that can automatically calculated:

Brightness. The brightness of a surface can easily be calculated by converting each pixel into a gray scale pixel where each gray scale value represents the brightness of the pixel. The overall brightness of a surface is defined by the average of all pixel's brightness.

SURF Features. A SURF detector defines interest points [1] indicating unique points in the image. The availability of an interest point can be used to automatically determine if there are changes in color on the surface. No interest points are found if the surface has a uniform color.

Edges. Edges might distort projected images on surfaces. Thus we use the Canny algorithm [6] to detect edges in an image.

Method

We conducted a repeated measures study with two independent variables: (1) the surface color on that an image is projected and (2) the texture of the surface. As dependent variables we measured the surface features i.e. brightness, number of SURF Features, number of detected edges, and the perceived PS of the participant using a 7-point Likert scale.

We constructed 15 wooden bricks ($20cm \times 30cm$) to represent five surface colors and three surface textures in all possible

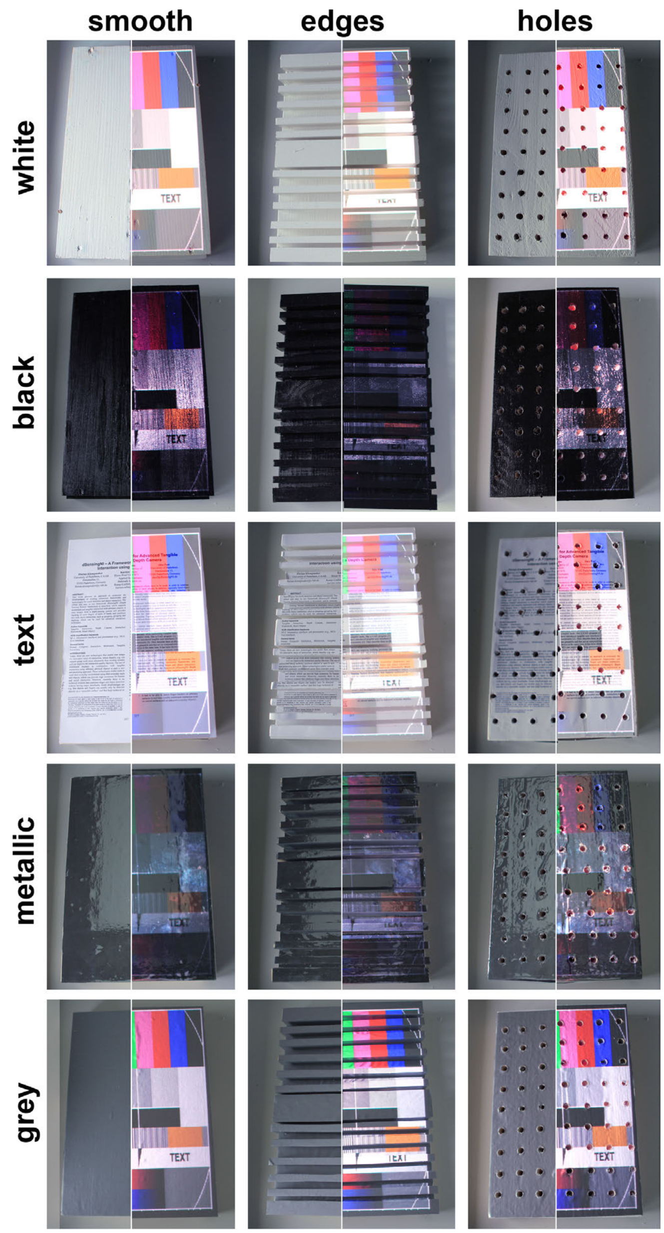

Figure 2. The wooden prototypes representing different surface textures and colors (left image sides). We projected a testing image onto each of the surface textures (right image sides).

combinations. As surface color we considered a good coverage of everyday surface colors using five different surface colors involving white, black, black text on white background, silver-shiny, and gray. Three surface textures were chosen to cover a broad range of everyday surfaces: flat, physical edges (e.g. a pile of books), and physical holes (as can be found on ceilings). The edges and holes were cut out or drilled into the wooden bricks. Furthermore, we constructed a stationary prototype consisting of an Acer K330 LED-projector and Microsoft Kinect that were both mounted 1.5*m* over a table. We only used the Kinect's RGB image to analyze the surface. For the projection, we used a test image containing the most common colors and a sample text. This test image was projected on all 15 wooden bricks, see Figure 2.

After explaining the course of the study and collecting the demographics, we showed our stationary setup to the participant. We started placing a wooden brick at the defined position on the table. After the Kinect analyzed the brick, the test image was projected on one of the 15 surfaces (placed underneath the projector in counterbalanced order). Then the participant was asked to look at the projection for 10 seconds. Afterwards, we asked the participant to rate the projection quality of the projected surface according to his or her opinion on a 7-point Likert scale. We repeated this procedure for all 15 bricks.

We recruited 15 participants (4 female, 11 male). The participants were aged from 10 to 31 years ($M = 22.46$, $SD = 5.78$). All participants were neither familiar with the prototype nor with the surfaces. The study took approximately 20 minutes per participant.

Results

We analyzed the subjective rating of the five surface colors using a Friedman test, which yielded a significant difference for the surface color, $\chi^2(4) = 150.315$, $p < 0.001$. The participants found the white surface most suitable ($M = 5.88$), followed by grey ($M = 4.97$) and text ($M = 4.51$). The least suitable color were the black ($M = 2.35$) and the silver-shiny ($M = 1.71$) surfaces. Pairwise Wilcoxon signed-rank post-hoc tests showed significant differences between all surface colors except text vs. grey (black vs. white $Z = -5.911$, $p < .001$, gray vs. white $Z = -4.202$, $p < .001$, text vs. white $Z = -5.728$, $p < .001$, silver vs. white $Z = -5.831$, $p < .001$, grey vs. black $Z = -5.710$, $p < .001$, text vs. black $Z = -5.692$, $p < .001$, silver vs. black $Z = -3.554$, $p < .001$, text vs grey $Z = -2.262$, $p = n.s.$, silver vs. grey $Z = -5.846$, $p < .001$, and silver vs. text $Z = -5.733$, $p < .001$). Afterwards, we analyzed the ratings of the surface textures for each color using the Friedman test and Wilcoxon signed-rank post-hoc tests with an applied Bonferroni correction for all surface colors, resulting in a significance level of $p < 0.017$.

White. On white surfaces, flat surfaces are most suitable for projection ($M = 6.80$, $SD = 0.41$), followed by holes ($M = 6.00$, $SD = 0.65$), and edges ($M = 4.86$, $SD = 0.63$). A Friedman test showed a significant difference for the white surface textures, $\chi^2(2) = 26.755$, $p < 0.001$. The post-hoc test showed that the differences between all types are statistically significantly different (flat vs. holes $Z = -3.477$, $p = .001$, edges vs. holes $Z = -3.314$, $p = .001$, flat vs. holes $Z = -2.972$, $p = .003$).

Black. Considering black surfaces, the analysis shows that flat surfaces are most suitable for projection ($M = 3.40$, $SD = 1.05$), followed by with holes ($M = 2.0$, $SD = 0.75$) and with edges ($M = 1.66$, $SD = 0.72$). A Friedman test showed a significant difference for the black surface textures, $\chi^2(2) = 21.922$, $p < 0.001$. Pairwise Wilcoxon tests showed that both the differences between flat and edges ($Z = -3.349$, $p = .001$) and between flat and holes ($Z = -3.216$, $p = .001$) are statistically significant. The difference between surfaces with holes and surfaces with edges is not significant ($Z = -1.406$, $p = n.s.$).

Grey. Regarding grey surfaces, the participants favored flat surfaces ($M = 5.60$, $SD = 1.29$), followed by with holes ($M = 5.33$, $SD = 0.89$) and with edges ($M = 3.93$, $SD = 0.96$). A Friedman test showed a significant difference for the grey surface textures, $\chi^2(2) = 17.925$, $p < 0.001$. Pairwise Wilcoxon tests showed that both the differences between flat and surfaces with edges ($Z = -3.093$, $p = .002$) and between surfaces with holes and with edges ($Z = -3.214$, $p = .001$) are statistically significant. The difference between surfaces with holes and flat surfaces is not significant ($Z = -1.232$, $p = n.s.$).

Text. The analysis of surfaces containing text showed that flat surfaces ($M = 5.20$, $SD = 0.94$) are favored by the participants, followed by surfaces with holes ($M = 4.73$, $SD = 1.03$), and surfaces with edges ($M = 3.60$, $SD = 1.05$). A Friedman test showed a significant difference regarding the texture types for the surfaces with text, $\chi^2(2) = 13.911$, $p = 0.001$. Pairwise Wilcoxon tests showed that both the differences between flat surfaces and those with edges ($Z = -2.965$, $p = .003$) and between those with holes and with edges ($Z = -2.631$, $p = .009$) are statistically significant.The difference between surfaces with holes and flat surfaces is not significant ($Z = -1.732$, $p = n.s.$).

Silver. Finally, we compare the textures of silver-shiny surfaces. Here, flat surfaces a preferred by the participants ($M = 2.06$, $SD = 0.96$), followed by surfaces with holes ($M = 1.80$, $SD = 1.08$), and surfaces with edges ($M = 1.26$, $SD = 0.45$). A Friedman test yielded a significant difference for the silver-shiny textures, $\chi^2(2) = 9.941$, $p < 0.007$. Pairwise Wilcoxon tests show that the difference between flat surfaces and surfaces with edges are statistically significant ($Z = -2.762$, $p = .006$). Both differences between flat surfaces and surfaces with holes ($Z = -1.069$, $p = n.s.$) and between surfaces with holes and surfaces with edges ($Z = -1.725$, $p = n.s.$) are not significantly different.

DISCUSSION AND DESIGN GUIDELINES

Our results show that the best surfaces to project content are white surfaces, which we know from common projection canvases. Surprisingly, projected content on grey surfaces is perceived to be better than content that is projected on white surfaces containing text. The quality of projection is perceived worse on black surfaces and on metallic surfaces. Furthermore, the study shows that projection on flat surfaces is always perceived to be better than projection on surfaces with

Figure 3. Prototype containing pico projector and simple web cam.

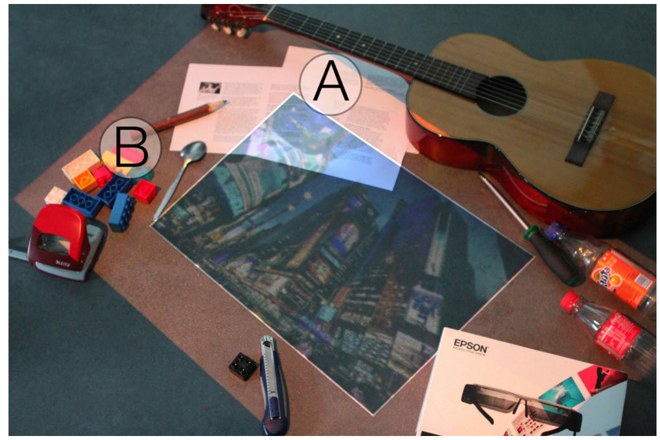

Figure 4. The prototype showing an image at a suitable position. The orange area is the whole projection area. (A) A feature-rich bright area is used for projection, too. (B) The area contains too many edges for a well perceived projection.

edges. The results indicate that surfaces with holes are perceived worse than flat surfaces for projecting content. These differences are significant for white and black surfaces. Additionally, the study indicates that surfaces containing edges are always perceived worse than flat surfaces and surfaces with holes. This trend is significant for white surfaces.

From the results of the user study, we provide design guidelines for automatically classifying a surface's suitability for projection based on the automatically calculated features.

1. Choose the brightest surfaces. A high brightness value of the surface is most important for a good projection.
2. Avoid surfaces with edges. Projecting on flat surfaces is always perceived better than projecting on surfaces containing edges.
3. Also consider feature-rich bright surfaces. In case, the projection area is not large enough, feature-rich bright surfaces (e.g. a piece of paper containing a text) can also be considered for projection. As feature-rich textures reduce the measured brightness, it is important to identify and consider them for rating a projection area suitability.

SYSTEM

We constructed a mobile prototype implementing the guidelines that we derived from the user study. Our system contains a Creative Socialize HD webcam and a Microvision handheld laser projector (see Figure 3). Both devices are connected to a workstation, which does the image processing as well as warps the content. The camera and the projector are firmly mounted to each other and calibrated to determine the extrinsic parameters.

The guidelines are implemented in our software that is written in `C#` using EmguCV[2] for computer vision and image processing. The webcam captures color images, which are converted into a gray scale image with a brightness range from 0 to 255. Furthermore, we applied the SURF [1] algorithm to detect feature points in each frame. We considered using a hessian threshold of 500. For detecting the edges, we used the Canny algorithm [6] with an lower threshold of 240 and an upper threshold of 255. As an initial threshold for the brightness, we used a value of 170. If an edge is detected, the area 5 pixels around the edge is marked. Areas, where a SURF feature point is detected are also marked to contain a feature point within 3 pixels around the point.

Our prototypical algorithm tries to find a rectangle with defined a minimum size. First, a matrix containing all brightness values is created. The brightness value is the initial projection suitability (PS) value. Second, if an edge was detected at a pixel, the algorithms subtracts 25 units from the PS-value. Third, if a feature point was detected on a pixel, the algorithm adds 10 units to the PS-value. In case a PS-value becomes negative, it is set to 0. The algorithm then tries to build a submatrix with a minimum size containing only pixels with a PS-value above a threshold of 170. If the minimum size could not be reached, a Gaussian convolution is used to smooth the feature points in the image, and then the algorithm is applied again. If there is still no rectangle with the minimum size, the required PS-value is reduced by 10. This procedure is repeated until an appropriate rectangle has been found. The thresholds were determined in accordance with the previously deduced guidelines. An example of the algorithms output can be seen in Figure 4.

CONCLUSION & FUTURE WORK

We present a novel approach for automatically finding suitable projection spots in everyday environments. Through a user study, we identified features of projection spots that are perceived to result in good image quality by the participants. The results show that white surfaces are most suitable for projection, followed by gray surfaces, surfaces containing text, black, and metallic surfaces. The results also indicate that the texture of the surface is important for projecting, as projection on flat surfaces is perceived to be better than projection on a surface with edges or holes. Based on the results of the study, we suggest guidelines for implementing an automatic detection of suitable projection surfaces. In a proof of concept implementation, we show their applicability.

[2] http://www.emgu.com (last access 04-19-2016)

In future work, we are planning to investigate further features, which can be used to automatically detect suitable projection spots. Inspired by related approaches [11, 12], we plan to add a depth sensing camera to determine flat areas and include them in the algorithm.

ACKNOWLEDGEMENTS

This work is funded by the German Ministry of Economics in the project motionEAP, grant no. 01MT12021E and the German Research Foundation within the SimTech Cluster of Excellence (EXC 310/1). The authors would like to thank Paul Brombosch for his work.

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