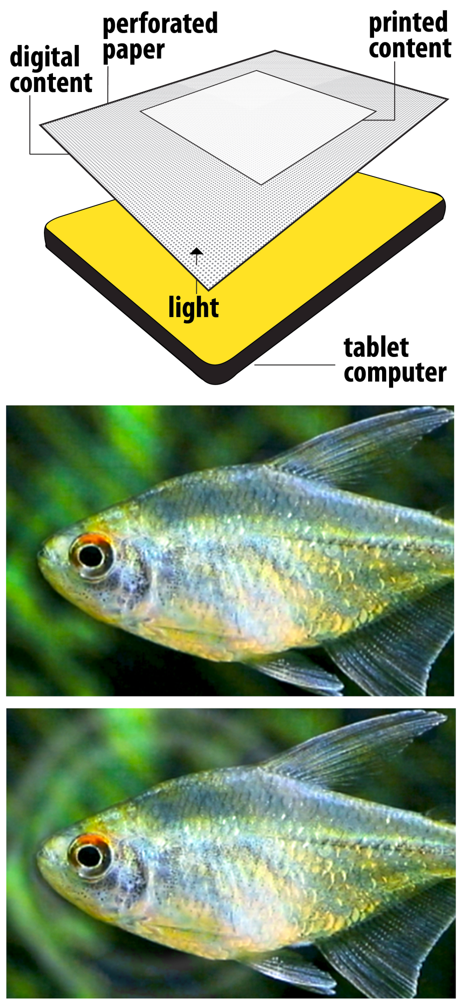

Perforated paper with a printed object placed on top of a tablet computer (top) displaying dynamic luminance animation and creating the illusion of a static object (middle) appearing perceptually dynamic e.g. waves on water (bottom).

Pinhole Paper: Making Static Objects Perceptually Dynamic with Rear Projection on Perforated Paper

Cuauhtli Campos
cuauhtli.campos@famnit.upr.si
University of Primorska
Slovenia

Klen Čopič Pucihar
Matjaž Kljun
klen.copic@famnit.upr.si
matjaz.kljun@upr.si
University of Primorska
Slovenia
Faculty of Information Studies in Novo Mesto
Slovenia

ABSTRACT

We explored the paper augmentation technique where a tablet computer is placed under the paper to modify its content appearance and create the illusion of a static object appearing perceptually dynamic. Our approach is based on the Deformation Lamps (DL) technique commonly used with front projection. However, we applied it to rear projection, which removes the need for a fixed hardware setup or handling and wearing dedicated hardware. The key challenge was to ensure the appropriate mixing of light reflecting from the paper (to see what is printed on the paper) and the light passing though the paper (to see what the tablet screen is projecting) since (i) a tablet screen is a relatively weak light source when being used in rear projection and (ii) commonly, paper has high opacity so the content from one side is not visible on the other side. In order to achieve the appropriate mixing of

MobileHCI '20 Extended Abstracts, October 5–8, 2020, Oldenburg, Germany

ACM ISBN 978-1-4503-8052-2/20/10.
https://doi.org/10.1145/3406324.3410534

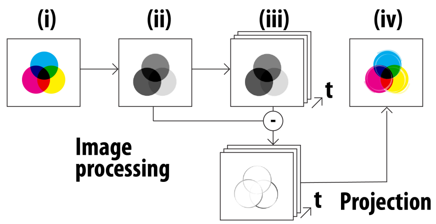

Figure 1: Schematic representation of Deformation Lamps technique: (i) printed image, (ii) greyscale of printed image, (iii) deformation sequence, (iv) final result [4].

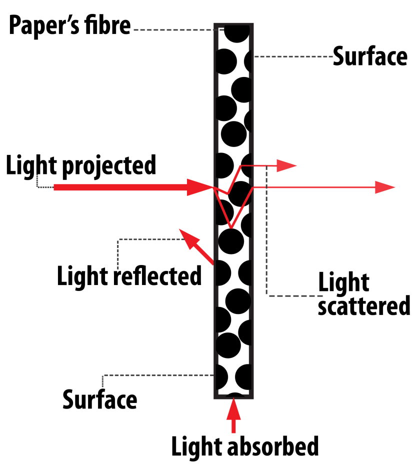

Figure 2: Light interaction in rear projection.

light, we reduced the opacity of the paper by perforating it (thus allowing more light to pass through), and modified the algorithm for generating dynamic luminance animation by adding gamma and brightness correction. The outcomes provide a guide on how to modify the paper and the algorithm in order to achieve the DL effect with rear projection using a tablet computer.

CCS CONCEPTS

• **Human-centered computing** → *Interface design prototyping*; *Interaction design process and methods*; *Interaction design process and methods.*

KEYWORDS

paper; perforated paper; digital augmentation; paper user interface; paper-based interfaces; paper computing; paper-digital interfaces

INTRODUCTION

Today, paper still maintains its importance as a medium despite rapid advancements and widespread usage of information-communication technologies (ICT). Its development over the centuries has enabled us to add text, images and colours,while paper's unique features make it an ubiquitous assets in the digital era. Paper is: *tangible* – users can feel paper textures; *portable* – paper can be easily carried around and is available almost everywhere; *affordable* – production is cheaper compared to other mediums (e.g. ICT); *manipulable* – paper can be folded, resized and reshaped with minimum effort; and *autonomous* – it is readily available to be used (it does not depend on electrical power).

Despite these features, and due to its own nature, paper cannot support digital content, such as animations, videos and audio. With the intent to reduce the gap between digital content and paper as a medium, researchers have added (i) paper features to digital hardware such as energy efficient e-book readers that can be used in most lighting conditions or digitising users' input with a stylus on a tablet computer [2], (ii) hardware to the paper such as NFC tags, conductive ink circuits, RFID antennas [5, 8], or (iii) digital content to the paper using hardware around it such as screens or Augmented Reality (AR) [7]. AR is the most common approach, which also preserves most aforementioned advantages of paper. Regardless of the abundance of different techniques to augment printed content, these still require users to handle or wear hardware (e.g. smartphones, HMDs) [6], or require elaborate setups of hardware around the user (e.g. projectors) [4], who can also occlude the augmentation.

In this work we explore the paper augmentation technique where a tablet screen is placed below the paper to modify its content appearance and create the illusion of a static object appearing perceptually dynamic. The approach is based on the Deformation Lamps (DL) technique where a pre-generated dynamic luminance animation is projected on top of a static image (Figure 1) [4]. Our approach is different as it applies a rear projection technique, which removes the need for a fixed hardware setup

Figure 3: Static images used. Top left: sunset. Bottom left: fish ("Diamond tetra, young individual in aquarium" by SOK is licensed under CC 4.0). Right: Woman with a Parasol - Madame Monet and Her Son (Monet).

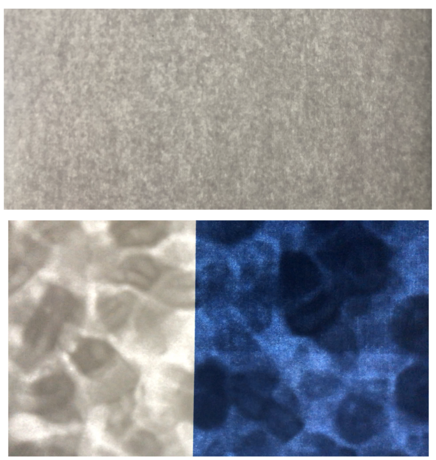

Figure 4: Copying paper. Top: clear copying paper with a white light in the back exposing structural formation. Bottom: the same effect on the paper with an black and white (left) and coloured image (right).

as well as handling or wearing dedicated hardware. The key challenge is to ensure the appropriate mixing of light reflecting from the paper (to see what is printed on the paper) and the light passing though the paper (to see what the tablet screen is projecting) since (i) a tablet screen produces a relatively weak light source when being used in rear projection and (ii) commonly, paper has high opacity so the content from one side is not visible on the other side.

EVALUATION OF THE PROPOSED APPROACH

For the rear projection we used the iPad Pro tablet computer placed below the paper. We tried to replicate the same effect as is produced in front projection with the Deformation Lamps (DL) technique [4]. This control appearance technique creates an illusion of a static object appearing perceptually dynamic by projecting a pre-designed dynamic luminance animation (see Figure 1). However, in front projection the light is reflected from the paper, which contrasts to the rear projection where some of the light scatters, some gets absorbed and some light needs to penetrate the paper before reaching our eyes (Figure 2). As such, the type of the paper used in rear projection can greatly affect the end result of the DL effect.

Evaluating unmodified paper. In order to investigate different types of paper we selected four samples listed in Table 1 with different grammage (the weight of paper expressed as grams per square metre) and coating. On each sample of the paper we printed three different images as seen in Figure 3: one using predominantly dark, non-vivid colours (sunset), one using predominantly light colours (Monet picture), and one using neutral colours (fish). We placed each of the 12 papers over the iPad running a tailored dynamic luminance animation for each image (e.g. ocean waves, wind and a circular wave). For all cases we used maximum screen brightness. The results were then individually visually assessed by four researchers in a room of 340 lux (765 cd) who wrote down notes and impressions.

Paper	Manufacturer	Coated	Grammage (g/m^2)	Identifier
Copying paper	Papyrus	No	80	CP80
Trace paper	Unknown	No	72	TRA72
Colour copy coated silk	Mondi	Yes	135	COA135
Multipurpose paper	Fabriano	No	240	FAB240

Table 1: Paper samples.

The comparing of notes showed that none of the papers in the study provided the desired results. In all but trace paper the amount of light coming though the paper was not sufficient, making animations not or barely visible. Structural formation of the paper (nonuniform distribution of fibres)

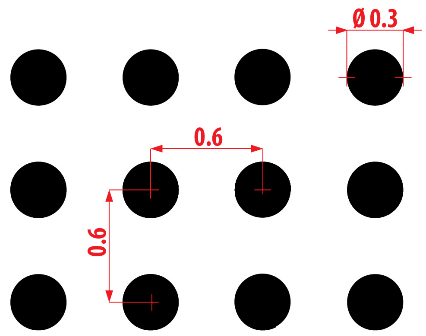

Figure 5: Perforation pattern used in our prototype. All units are in millimetres.

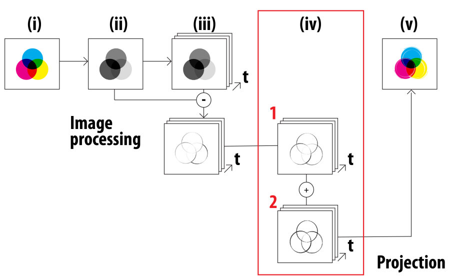

Figure 6: In step (iv) we implemented a subroutine with two steps: (1) applied gamma correction with 1.75; and (2) adjusted brightness by adding a positive constant (c=50) to all pixel values greater than 0.

also generated an unwanted effect of adding a texture to the printed image (Figure 4). Trace paper had the lowest opacity in the study, however it did not perform as anticipated. We found it difficult to print clearly visible images on it. Trace paper also had the aforementioned problems with structural formation. In none of the cases could we produce an adequate illusion of a static object appearing perceptually dynamic.

Changing optical properties of paper with perforation

Our next step was to try and modify physical properties of the paper and make it more appropriate for rear projection. According to Jurič et al. [3], paper has several properties grouped into three major groups: (i) Structure and composition (basis weight, bulk and density, caliper, hardwood percentage, sizing, porosity, roughness), (ii) Optical properties (brightness, fluorescence, gloss, opacity, whiteness, shade), and (iii) Electrical and Thermal properties (structural and surface resistance, dielectric constant, thermal properties, conductivity and porosity). We were interested in the optical properties of the paper; in particular, how to reduce the opacity of the paper whilst maintaining good reflectance characteristics.

Opacity plays an important role in back projection since changes in opacity will change the amount of light that can pass through the paper [3]. This property is influenced by thickness and degree of bleaching of the paper fibres [1, 3]. In order to decrease the opacity of the paper we based our approach on the principle of stenopeic (or pinhole) glasses that instead of lenses use an opaque sheet of material perforated by a series of pin-sized holes. Each hole allows only a very narrow beam of light to pass through. The sum of contiguous light that passes through adjacent holes enables viewers to clearly visualise what is on the other side.

To accomplish this, we perforated paper using a laser engraver Speedy Trotec 400 with a 1.5-inch lens (recommended for cutting thin materials such as paper). The perforation pattern used is seen in Figure 5. The holes are separated by each other in a proportion 1:1. The multipurpose paper with 240 g/m^2 most suitable for perforation was chosen for this purpose. We experimented with different hole diameters ranging from 1 mm to 0.2 mm since this is the lowest achievable size with the engraver used. As before, each perforation was individually assessed by four researchers. Perforation with 0.3 mm holes was chosen as the best result since the perforation with 0.2 mm holes had some holes imperfectly cut, making the perforation non-uniform.

GENERATING DYNAMIC LUMINANCE

As before, four researchers compared the effect of the DL technique using rear projection with the three images printed on the multipurpose 240 g/m^2 paper perforated with 0.3 mm holes. They compared three different methods for generating dyanmic luminace animations (Figure 7): (i) SDL - standard dynamic luminance generated according to the DL technique, (ii) RA - raw animation

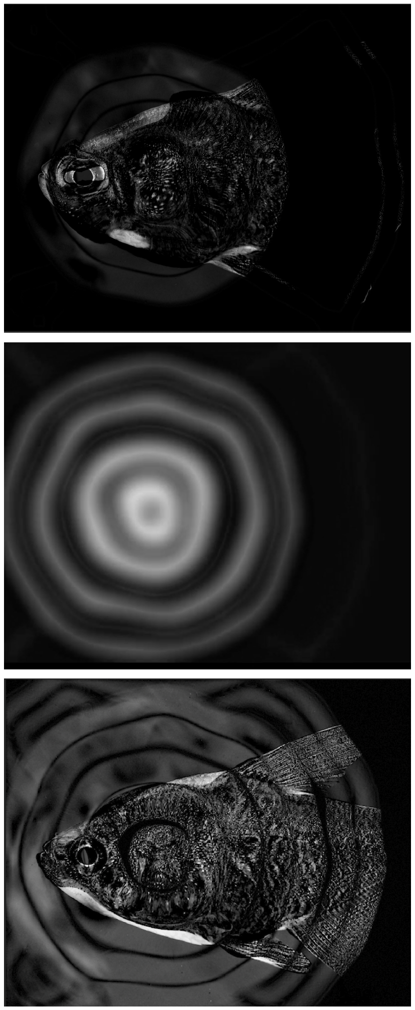

Figure 7: Dynamic luminance animations. Top: Standard Dynamic Luminance (SDL). Middle: Raw (RA). Bottom: Extra Brightness (EB).

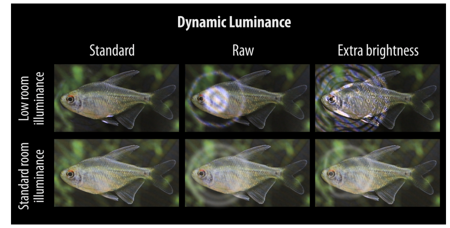

Figure 8: Dynamic luminance comparison under two light conditions and three different methods for generating dyanmic luminace animations.

without image subtraction, and (iii) EB - standard dynamic luminance with gamma correction and brightness adjustment. In order to create the EB animation, we added two extra steps to the original Deformation Lamps algorithm to adjust the brightness of the dynamic luminance animation.

Step 1: We performed gamma correction on our black and white image such that all pixels n are:

$$(\forall n \in [0, 255])(\exists \gamma > 1, \gamma = const) \therefore n^{\gamma} \leq 255$$

Step 2: We adjusted image brightens by a constant such that:

$$(\forall n \in (0, 255])(\exists c > 0, c = const) \therefore (c + n) \leq 255$$

Image processing was accomplished with After Effects CC. Step 1 was implemented using *Levels* function with *Gamma* = 1.75, *InputBlackValue* = 0. *InputWitheValue* = 255, *OutWhiteValue* = 255, *OutBlackValue* = 0. Step 2 was completed with *Brightness Contrast* function with *Contrast* = 0 and *Brightness* = 50.

All three three methods for generating dyanmic luminace were observed under two lighting conditions: low illuminance of 110 lux (247 cd) and standard illuminance of 340 lux (765 cd). In standard room illuminance the SDL animations are barely visible, RA faces problems of projection dominating over printed image, while EB produces the best result comparable to front projected DL. In low room illuminance dyanmic luminace animations of EB and RA dominate over the printed image and DL performs best. In the case of EB, the problem of animation dominance could be easily addressed by adjusting screen brightness based on sensed room illuminance. As such, EB is the only technique that can work in both standard and low illumination.

CONCLUSION AND FUTURE WORK

We created a paper augmentation technique where a tablet screen is placed below the paper to modify its content appearance and create the illusion of a static object appearing perceptually dynamic. We base our approach on the Deformation Lamps technique (DL). However, to make the illusion work we modified: (i) the DL method of generating dynamic luminance animation by adding gamma and brightness correction ; and (ii) the optical properties of $240g/m^2$ paper by perforating it with a grid of 0.3 mm holes. The perforation decreased the opacity of the paper, allowing more light to pass through while preserving all other paper properties. The outcomes provide a guide on how to modify the paper and the DL algorithm in order to create an illusion of a static object appearing perceptually dynamic with rear projection using a tablet computer.

In the future we will try to use different patterns (e.g. the chess pattern). We also plan to run a bigger user study comparing the the effect of DL technique using rear and front projection with the same conditions as in our initial study described in this paper in order to find out which setup produces a most realistic effect. We also plan to look into ways of tracking the paper position on tablet screen in order to automatically align animation with printed content as well adjusting the screen brightness based on sensed illuminance in the environment. Lastly, we will explore smaller perforations (< 0.3 mm) than one achieved by the laser engraver used in this study.

ACKNOWLEDGMENTS

The authors also acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement 739574) under the Horizon2020 Widespread-Teaming programme and the Republic of Slovenia (Investment funding of the Republic of Slovenia and the European Union of the European Regional Development Fund). The research was also supported by Slovenian research agency ARRS (P1–0383, J1–9186, J1-1715, J5-1796 and J1-1692).

Links

Github repo:
https://github.com/Cuauthli86/pinholePaper
Video demo:
https://youtu.be/-ecPw3ML9PQ

REFERENCES

[1] J. Borch, M. Lyne, R. Mark, and C. Habeger. 2001. *Handbook of Physical Testing of Paper.* Number v. 2. Taylor & Francis. https://books.google.si/books?id=qa-I8QAOUL8C

[2] D. T. Clark, S. P. Goodwin, T. Samuelson, and C. Coker. 2008. A qualitative assessment of the Kindle e-book reader: Results from initial focus groups. *Performance Measurement and Metrics* 9, 2 (2008), 118–129. https://doi.org/10.1108/14678040810906826

[3] I. Jurič, I. Karlović, I. Tomić, and D. Novaković. 2013. Optical paper properties and their influence on colour reproduction and perceived print quality. 28, 2 (2013).

[4] T. Kawabe, T. Fukiage, M. Sawayama, and S. Nishida. 2016. Deformation lamps: A projection technique to make static objects perceptually dynamic. *ACM Transactions on Applied Perception* 13, 2 (2016), 1–21. https://doi.org/10.1145/2874358 arXiv:1509.08037

[5] K. Klamka and R. Dachselt. 2017. IllumiPaper: Illuminated interactive paper. In *Conference on Human Factors in Computing Systems - Proceedings*, Vol. 2017-May. Association for Computing Machinery, 5605–5618. https://doi.org/10.1145/3025453.3025525

[6] M. Kljun, Matjaž ; Čopič Pucihar, Klen; Alexander, Jason; Solton, Paul; Grubers Jens; Ducasem, Julie; Kopačin, Barbara; Weerasinghe. 2019. Augmentation not Duplication : Considerations for the Design of Digitally-Augmented Comic Books. *In Proceedings of ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '19).* (2019), 12.

[7] P. Luff, G. Adams, W. Bock, A. Drazin, D. Frohlich, C. Heath, P. Herdman, H. King, N. Linketscher, R. Murphy, M. Norrie, A. Sellen, B. Signer, E. Tallyn, and E. Zeller. 2007. Augmented paper: Developing relationships between digital content and paper. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 4500 LNCS, May 2014 (2007), 275–297. https://doi.org/10.1007/978-3-540-72727-9_13

[8] J. Qi and L. Buechley. 2010. Electronic popables. *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction - TEI '10* (2010), 121. https://doi.org/10.1145/1709886.1709909