

Printing Secure Automatic Receipts with Activating Ink

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and others from the Scantegrity Project...

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Abstract

The Scantegrity voting systems requires a printer to create hidden codes that can be revealed by a ballot marking pen only. The codes are used as confirmation numbers to create an automatic privacy preserving receipt for each voter. We discuss the techniques used to make the marks irreversible, and make the codes unrecoverable in any other way on the printed ballot.

This documents current progress in our work, which is ongoing. This document is subject to change.

1 Introduction

Scantegrity is an enhancement for existing optical scan paper ballot systems. It provides E2E properties by allowing voters to note codes on the ballot and check for them online. Each voter marks her ballot just like a conventional optical scan ballot, but using a special ballot marking pen. Marking a selection with this pen makes legible an otherwise activating pre-printed confirmation code.

Voters can look up their ballot serial numbers online and verify that their confirmation codes are posted correctly. Correctness of the final tally with respect to the published codes is proven by election officials in a manner that can be verified by any interested party. Thus, compromise of either ballot chain of custody or system software cannot undetectably affect election integrity.

The design behind Scantegrity requires a number of novel improvements to current optical scan voting system designs. The most visible change is printing technology that can print codes that appear after marking the ballot. While not the original intent, a side effect of this technology is that the ballot marking pen only allows marks in permitted locations.

2 Background

The ability to recover the hidden codes on the ballot could cause two problems in Scantegrity:

1. False claims of electoral fraud, through claiming that codes were not posted properly, or by claiming an uncast ballot was cast.
2. Violation of ballot secrecy, by recording what each code means for each ballot and asking the voters for their receipts..

Our approach to solve these issues involves using activating ink, which turns black when it comes in contact with a developer ink causing a chemical reaction. This approach was chosen over covering methods (e.g. scratch off pads, stickers, etc) because it interferes the least with how voters currently use optical scan systems, the information is hidden immediately when printed, it allows us to place/move marking locations on the fly, and it was easy to implement cost effectively with replaceable ink cartridges by swapping out the colored ink cartridges for invisible ink cartridges.

3 Requirements

Ballot scanning works by detecting dark marks in prespecified locations, so by printing the background in the activating ink, the scanner would detect the dark marks while characters appear in white in the marking bubbles. Thus, in order to work, the activating ink must be of low visual contrast initially to the print medium (i.e. the paper). After it has activated fully from an irreversible chemical reaction, it must be of high visual contrast to the print medium such that it is easily distinguishable as black by the scanner and by the human eye.

Any liquid (though not necessarily pigmented) will subtly change the reflective characteristics of the print medium through the printing process, meaning the presence of the background printed in ink also will still potentially be visually perceptible. Additionally, for privacy reasons we want the codes to disappear several minutes after voting. For this reason we use a reactive foreground ink with a slower activation time. Ideally, we want to achieve the following properties:

- The foreground and background inks are color-matched to the initial pigmentation characteristics of each other such that the inks are visually indistinguishable.
- Contact with the developer ink will initially produce negligible pigmentation change in the foreground ink so as to be in high visual contrast to the background ink such that the inks become readily visually distinguishable from each other.
- After some time (e.g. 5 minutes), the foreground ink will complete a slower activation with the developer ink such that it is again indistinguishable from the activated background ink.

4 Methods

We have been unable to achieve our desired properties perfectly in practice, but through experimentation we have developed tools that allow us to overcome many of the issues. The printer is particularly problematic. Nozzles on the printer can cause different consistencies in

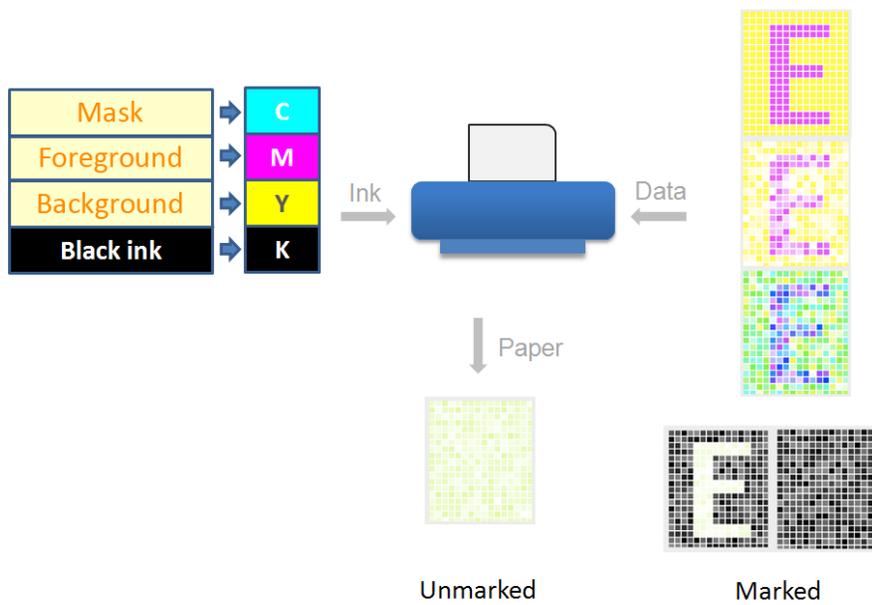


Figure 1: **Invisible Ink Printing Process.** The inks are filled in the color cartridges for the printer. The right side illustrates the texels, randomized texels, and randomized texels with a mask. When the ballot is printed, the inks are indistinguishable. When the inks react with the developer, a letter is visible, and after some time the inks are again indistinguishable.

the ink when printed onto the paper. If the inks run up against each other nozzle alignment can cause a visible offset in the printed ink. The printer drivers will occasionally adjust the intensity of the inks printed to the page. The inks, although the color is indistinguishable, have a very subtle contrast to each other, and over time our inks changed colors.

One interesting observation is that the intensity or amount of ink printed to the paper directly controls the contrast that the inks have to each other.¹ Using this we have come up with the following techniques for strengthening the security properties of the inks:

1. We divide the oval into square tiles called texels. Each texel is entirely printed with either reactive or slow-reactive ink, but never with a combination of them.
2. A small gap is left between any two adjacent texels, such that when two adjacent tiles are printed with different inks, the two inks do not overlap.
3. The intensity of each texel is printed at random between 2 different intensity levels.
4. The addition of a third type of ink that we call a masking ink. It is colorless but has high fluorescence. Masking ink is the last ink sprayed onto the paper. We add random amounts of masking ink to all texels of the oval.
5. An automatic “color matching” system that allows the user the enter values at the beginning of the printing to minimize the differences in intensity and maximize the effectiveness of the randomization technique.

5 Results and Discussion

We implemented the first 3 techniques and they are effective under fluorescent (black) light, regular light with a microscope, and close up images taken with a 10.2 megapixel digital camera. The color matching system would require development of a print test sheet and model that accurately allows the user to identify contrast to be effective.

There are still issues with the ink ageing over time. There are also a number of attacks that have not been tried:

1. Tape lifts to take a sample and develop it.
2. Reactions to linearly & circularly polarized and/or oblique light, or xrays.
3. Dusting it with powders to see different electrostatic or Van der Waals attractions to the reactive agent.
4. Translucent liquids and solids with different colors and refractive indices.
5. Surface energy effects (e.g. adding oil/grease and rubbing)

¹It is unclear if this property is normal or a function of the particular inks we are using.

Clearly, most chemicals (if not all) can be distinguished from one another through a sufficiently sophisticated test. Our assumption is that, like cell phones and other recording devices, it is impractical for voters to bring the necessary equipment or perform the necessary test undetectably in a short period of time. Also, it is expected that because the chemical composition of the two inks is similar, it should be possible to make such analysis difficult without sensitive tools.

6 Future Work

We intend to finish an automatic color matching system and the masking agent, and also to try the identified attacks where it is feasible to do so. We consider the activating ink system practical, but will also pursue more sophisticated analysis. One class of such tests is electromagnetic spectroscopy, which would quantify the differences across a sample under a variety of different forms of light. ²

7 References

There's a patent that notes that an activating ink would improve system usability. We could find no implementation of it:

http://www.google.com/patents?id=zIyeAAAAEBAJ&pg=PA3&dq=ballot+scanner&source=gbs_selected_pages&cad=2#v=onepage&q=ballot%20scanner&f=false

Publication number: US 2004/0195322 A1 Issued patent: 7021539 (Issue date Apr 4, 2006)

We were told of another patent that uses activating ink to complete bar codes. Haven't found it, yet, and will have to do more searching.

²http://en.wikipedia.org/wiki/Electromagnetic_spectroscopy