Illuminated Interactive Paper with Multiple Input Modalities for Form Filling Applications

Figure 1. Maintenance Form Filling Application: Our smart form system supports maintenance workers to create error reports faster by providing real-time status information for network machines on the paper itself using novel printed electronics.

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Abstract
In this paper, we demonstrate IllumiPaper: a system that provides new forms of paper-integrated visual feedback and enables multiple input channels to enhance digital paper applications. We aim to take advantage of traditional form sheets, including their haptic qualities, simplicity, and archivability, and simultaneously integrate rich digital functionalities such as dynamic status queries, real-time notifications, and visual feedback for widget controls. Our approach builds on emerging, novel paper-based technologies. We describe a fabrication process that allow us to directly integrate segment-based displays, touch and flex sensors, as well as digital pen input on the paper itself. With our fully functional research platform we demonstrate an interactive prototype for an industrial form-filling maintenance application to service computer networks that covers a wide range of typical paper-related tasks.

Author Keywords
Digital pen and paper; electroluminescence; augmented paper; visual feedback; Anoto; form filling; printed electronics.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation]:
User Interfaces. - Graphical user interfaces, Input devices and strategies, Interaction styles, Prototyping

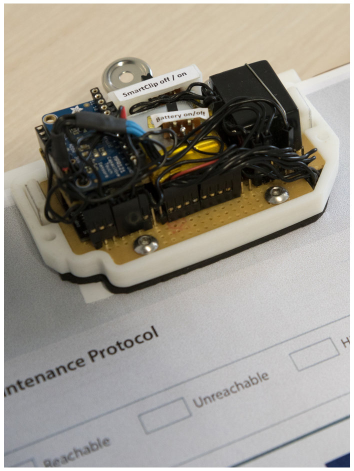

Figure 2. IllumiPaper Smart Clip: The paper clip provides eight EL displays, four resistive and twelve capacitive touch channels.

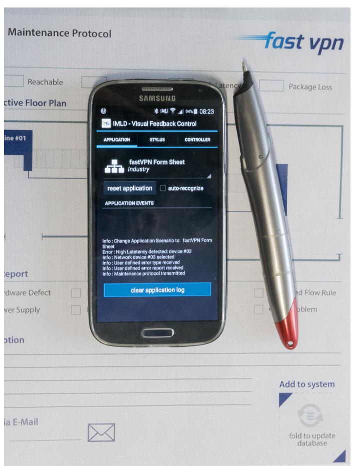

Figure 3. Demonstration Setup: We use an Android application to handle all business logic of the respective application scenario.

Introduction and Background

The use of paper and writing is a major cultural achievement that has maintained its importance even in today's information age [4]. Interaction with paper feels simple and natural and has haptic qualities that users may prefer. Additionally, in some professional use cases, paper documents have to be archived for legal purposes. For example, in medical or law enforcement settings or in the maintenance and auditing of critical infrastructure, a written record has to be kept. On the other hand, vast amounts of digital data can be easily stored, filtered, analyzed, and shared. Also, depending on the context and the user's requirements, digital information can be flexibly presented in many different forms. This powerful computing functionality should be combined with real paper for added digital value, while maintaining the unique properties of paper.

The development of digital pens (e.g., Anoto technology) laid the basis for recognizing and analyzing handwritten text on paper, but the provision of visual feedback, e.g., to communicate pen or system states, as well as rich interaction modalities in addition to digital pen input remain two important challenges. A wide range of modalities have been proposed (see [2] for an overview) but feedback is often not *directly* integrated into the paper, which would allow to provide it close to the ink and directly related to the content itself.

Although screens such as flexible OLED or E-Ink displays enable rich interactions and will become available in the long term, we argue that these display types will perhaps always lack some of natural paper's properties and might be too expensive and complex for replacing paper entirely.

In contrast, we see high potential in emerging printed electronics and displays technologies as an important enabling factor towards seamlessly integrated digital paper enhancements. Printed technologies, e.g., customizable electroluminescent displays [3], provide ultra-thin, flexible, and versatile input and output capabilities on standard paper and preserve almost all unique paper properties.

IllumiPaper Research Platform

In this work, we built on IllumiPaper [2], an interactive system for visual paper augmentation without additional projector setups or display devices using novel printed electronics and thin-film display technologies. We extended IllumiPaper with multiple natural input channels on the paper itself. In addition to digital pen interactions, we integrated capacitive touch and paper bend gestures. Furthermore, we contribute a streamlined fabrication process based on conductive inkjet- and electroluminescent screen-printing. We present this system by means of a prototype for a form filling application to support the maintenance of industrial networks, one particular use case that stands to benefit from the combined advantages of physical paper documentation and digital information (see Figure 1).

Technically, our setup consists of a smart controller (see Figure 2) that can be seamlessly clipped to our augmented paper sheets (see Figure 4), a digital pen, and a mobile Android app (see Figure 3). Depending on the application, the mobile app controls all paper-integrated displays and their behavior based on the current state of the capacitive touch sensors, resistive flex sensors, or digital pen values[1].

First llumiPaper sheets used paper-attached electroluminescent (EL) panels that are cut or foil-masked. In this paper, we improve the IllumiPaper system by printing the paper sheets with advanced fabrication methods to increase the degree of quality and integration. In addition,

[1] Further fabrication details are available on our project website: https://www.imld.de/illumipaper/

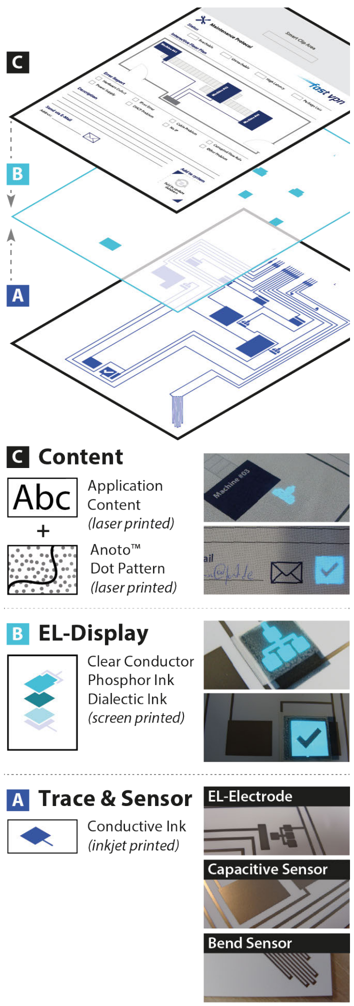

Figure 4. Augmented Paper: Printed IllumiPaper with three layers: A conductive printed trace and sensor **(A)**, a screen-printed EL-display **(B)** and a digital pen-enabled content **(C)** layer.

we integrate multiple input modalities to enhance the user experience beyond pen input and support additional natural complementary techniques, such as probing (see Figure 5).

Fabrication of Interactive Illuminated Paper

In order to fabricate completely printed paper illuminations and sensors, we use technologies that are easy-to-use, ultra-thin, flexible, and robust. In particular, we employ several different kinds of printing methods: inkjet, laser, and screen printing. For our design, we require three printed functional layers (see Figure 4, A-C) that we will briefly describe in the following section:

Trace & Sensor Layer (A). The IllumiPaper research platform provides a smart clip controller that can be seamlessly attached to a digitally-enabled paper to control the paper-integrated displays and sense capacitive and resistive sensors. All signal traces are integrated inside the clip that seamlessly establishes a physical connection to the conductive paper layer when it is closed. We realize all paper traces and back-electrodes for the paper-integrated EL displays with a conductive inkjet-printing process [1]. In addition, we integrated printed flex-sensing patterns [5] that change their resistance during a deformation to enable paper bend interactions. Furthermore, capacitive touch fields are used to enable touch input (see Figure 5, A+B). All traces and sensors are printed with a standard inkjet printer whose cartridges we filled with conductive ink[2].

EL-Display Layer (B). To realize our paper-integrated illuminations, we screen print electroluminescence displays [3] by adding a dialectic, a blue high bright phosphor, and a clear conductor layer[3] on top of our previous conductive inkjet-printed electrode layer which also defines the final form of the segment display. The color of the EL-displays is pre-defined with the fabrication process and can be varied by using different dialectic and phosphor substrates. The displays shine bright through the content layer and are powered with AC voltage by an inverter of the smart clip.

[2]**Mitsubishi Imaging**. Silver Nanoparticle Ink (NBSIJ-MU01). http://www.mitsubishiimaging.com/

[3]**Gwent Electronic Materials Ltd.** Materials for electroluminescent panels are available at http://www.gwent.org/

Content Layer (C). As a third layer, we use 120 g paper onto which we printed the form filling application content and an Anoto-Pattern[4] to enable digital pen interaction. We glue this layer onto the previously printed trace and display paper with adhesive spray and thereby completely protect the paper-integrated illuminations and sensors from both sides. For thinner paper sheets, we have also successfully printed all traces and displays (in a reverse printing order) on one single paper sheet.

Application: Maintenance Forms

With our prototype we demonstrate the application of our IllumiPaper technology to computer network maintenance tasks and reports. In our envisioned usage scenario, a maintenance engineer is doing routine check-ups of a factory's IT infrastructure (see Figure 1). IllumiPaper supports him or her in looking up currently flagged issues of network nodes and in filling out error reports. By combining the qualities of paper documents with the advantages of digital information processing, support tickets can easily be created in the field but also, at the same time, saved in a physical, immutable form.

The prototype works as follows: The maintenance engineer uses error reporting slips that are enhanced with IllumiPaper technology. The upper part of each slip gives an overview of the factory's floor plan and all devices that the

[4]**Anoto**. Digital Writing Solutions. http://anoto.com/

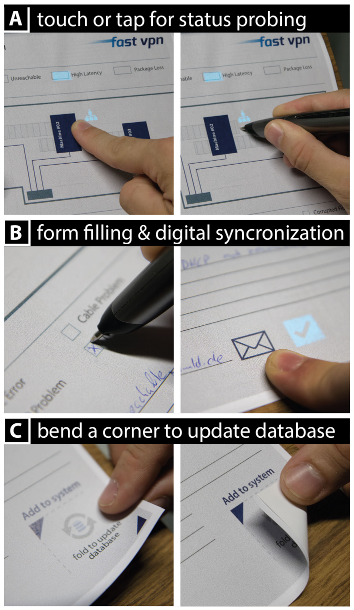

Figure 5. Form Filling Actions: Smart status requests for current network status **(A)**, real-time syncronization of the form and visual feedback for send button **(B)**, and flex sensors as a explicit trigger action to update the maintenance report **(C)**.

engineer is responsible for are shown in this overview. Illuminated icons highlight hardware for which errors have been detected. By selecting a device on the floor plan, simply by touching or pen tapping it (see Figure 5, A), additional information on the type of error is shown above. This is an example of the underlying fundamental feedback design of a smart request, particularly a *smart probing* approach. In this way, we support the maintenance worker by visualizing the network status information dynamically. After checking the device, the maintenance engineer can write his or her report on the slip. This handwritten text is digitized through the use of Anoto technology. After finishing the report, a copy of the report can be sent via mail, e.g., to inform an expert about a specific hardware fault (see Figure 5, B). Alternatively, the engineer can save the digital copy of the report by using a simple folding gesture, metaphorically turning to a new page (see Figure 5, C). Independent of the input modality, the maintenance protocol highlights a checkmark to confirm the user action. The use of this *control element feedback* ensures that the engineer can be sure that the report is sent correctly.

Conclusion

We presented the fabrication and application of smart form filling sheets based on the IllumiPaper research platform using emerging printed, segment-based display technologies. We extended IllumiPaper with multiple input channels and described the setup and our new, simplified fabrication process in detail. Additionally, we introduced the use case of smart maintenance forms, which covers a wide range of typical paper-related tasks. With our fully functional interactive prototype, we demonstrate techniques for detecting, describing, and transmitting error reports for, e.g., industrial networks. Our approach aims to benefit from the combined advantages of physical paper documentation and digital real-time information such as dynamic device status probing. With this demonstration, we aim to show the promising potential of IllumiPaper for more powerful and dynamic reports in form filling workflows.

For future work, we plan to technically improve our prototype with colored EL-displays as well as more display channels. We also plan to evaluate our concepts in expert interviews and field studies.

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