TUIs in the Large: Using Paper Tangibles with Mobile Devices

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Abstract
Tangible user interfaces (TUIs) have been proposed to interact with digital information through physical objects. However being investigated since decades, TUIs still play a marginal role compared to other UI paradigms. This is at least partially because TUIs often involve complex hardware elements, which make prototyping and production in quantities difficult and expensive. In this paper we present our work towards paper TUIs (pTUIs) – easily makeable interactive TUIs using laser-cut paper, brass fasteners, metal bands, mirror foils, and touch screen devices as platform. Through three examples we highlight the flexibility of the approach. We rebuilt the seminal work URP to show that pTUIs can replicate existing TUIs in DIY manufacturing. We implemented tangible Pong being controlled by paper rackets to show that pTUIs can be used in highly interactive systems. Finally, we manufactured an interactive Christmas card and distributed it to 300 recipients by mail to show that pTUIs can be used as apparatus to explore how pTUIs are used outside the lab in real life.

Author Keywords
Tangible; TUI; paper prototype; manufacturing.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

Introduction

Tangible User Interfaces (TUIs) are known for more than 25 years [4]. In the early years the main user groups of TUIs were researchers in the lab or the participants of lab-based user studies. An example is the seminal Urp, an urban planning system consisting of 3D building models and an interactive surface that displays shadows and wind flows according to the models' position. A prototype has been built to demonstrate the Urp concept [7], but it has never been widely used outside the lab. During the last decade TUIs, such as the Reactable [5], have been built as products for being used outside the lab. However, such examples TUIs remained individual pieces of rather than mass products. More recently, commercial TUI products were released, for instance interactive puzzle units that recognize their nearby units[1] or TUIs that can be recognized when being placed in front of a camera-equipped mobile device for extending the device's interaction space[2].

Overall, researchers built highly innovative TUIs, which often require a high-fidelity combination of hard- and software. In our work we are interested in investigating TUIs with a large number of users. Therefore, we aim for low-fidelity TUIs to test them with a many users and high external validity [3] through mobile devices that are used as the software component of our TUI approach.

To enable easy TUI distribution into the large as well as low-cost TUIs, we propose the idea of paper TUIs (pTUIs). These special kinds of TUIs utilize manual assembly from end users and are enriched by their mobile devices making them interactive. The main design considerations is that each pTUI can be send via mail (i.e., fits into an envelop) and is easily mass producible (i.e., very cheap producible or producible by the end-users themselves, e.g. through scissor- or laser-cutting a paper template for the TUI). Thus, pTUIs can easily be distributed to a large number of potential participants.

The contribution of this paper is twofold. First, we present three easily self-producible interactive paper TUIs that extend mobile devices. Second, we document the delivering procedure of one pTUI via mail, including the pTUI distribution success shown by accesses of the according website as well as end users' feedback about their pTUI production.

Paper TUIs

pTUIs are low-cost interactive TUIs, whereby the tangible components are mainly made out of thick paper. To make pTUIs interactive, we include brass fastener and metal foil that allows a mobile touchscreen device, which runs a specific web application, to detect the position of the pTUI on the touchscreen. In the following we describe the hardware as well as the software part of pTUIs.

Hardware

For the hardware unit, we mainly use thick paper or cardboard as construction material. Paper has the advantage of being easily processable with fabrication tools such as laser-cutter or even by hand using scissors and cutters. Moreover, it is easy to build 3D structures by folding and combining individual paper pieces.

To make the pTUI interactive, we exploit the users' mobile devices to use the paper units as tangible widgets. Current touchscreens of mobile devices use capacitive sensors for locating and tracking fingers on the screen. Previous work showed how this technology can also sense tangible elements on capacitive screens. One example are

[1] http://farewell.sifteo.com/
[2] https://www.playosmo.com/

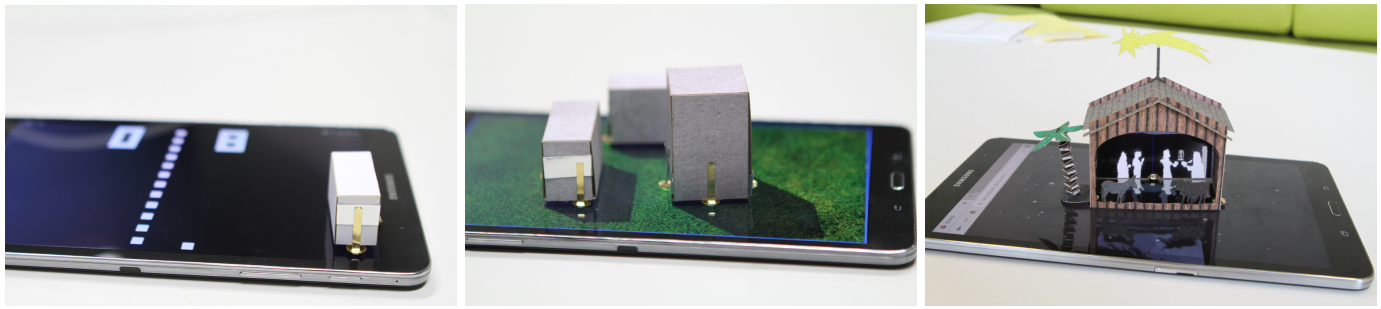

Figure 1: The three examples of pTUIs: Paper Pong, Paper Urp, and interactive Christmas card.

CapWidgets. CapWidgets are physical rotary aluminum knobs built for interacting with mobile content through physical widgets [6]. They transfer the user's ground potential to the capacitive touchscreen surface through two metal plates on the bottom of the widgets that touch the device's touchscreen. Capstones extend the approach of CapWidget by allowing to stack touchscreen TUI widgets on top of each other [2]. Sketch-a-TUI, another extension of the CapWidget idea, uses cardboard forms with drawn lines of conductive ink to make the forms recognizable on capacitive touchscreens [9]. While the CapWidgets approach requires the transfer of the human body's capacitance to a touchscreen, PUCs are touchscreen widgets that work without been touched through connecting conductive pads with a conductive acrylic bridge [8].

While the concept proposed with PUC is a highly exciting direction for future work, Voelker et al. reported a detection rate of 90%-100% for their sophisticated prototypes. As we are uncertain if the same level of detection rate can be achieved by end users' manufactured TUIs containing low-cost components we follow an approach similar to CapWidgets. Aiming to distribute pTUIs in the large and thus, striving for low-cost, we connect brass fasteners with a metal band that transfers the capacitance of the user's touch to the capacitive sensor of a touch-enabled device. This construction contains a number of conductive pins for the pTUI, those positions can be recognized by a web application as touch input. We use brass fasteners rather than conductive ink as the bottom of our construction is left out so that an animation is visible. Two conductive pins provide a little horizontal area for recognizing the size and position of a cardboard rectangle. Using three pins allows even to recognize the orientation of the pTUI if necessary.

Software

As supplement to the physical pTUI components, we developed a web application that tracks the pin positions and displays additional content on the screen of the mobile device accordingly. The web application uses the HTML5 Touch Event API[3] to detect the position of the conductive pins. When a new touch event is triggered the API returns the pixel coordinates of all active touch

[3]The API is available on all modern mobile web browsers.

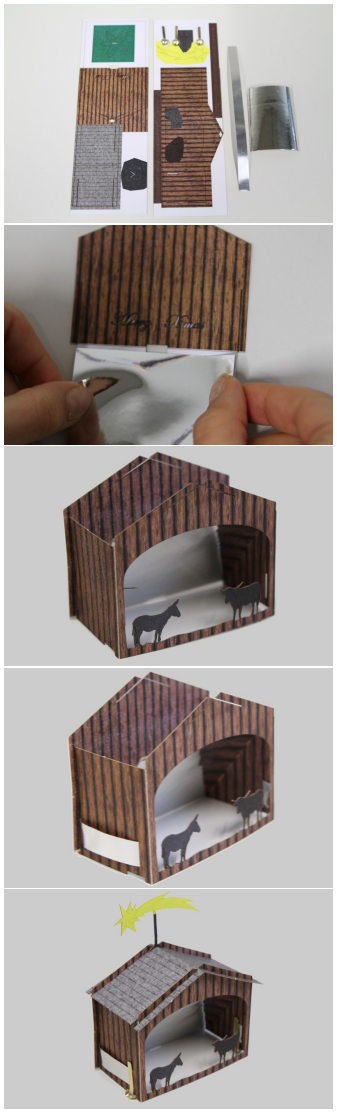

Figure 2: Images from the construction instructions.

points. For pTUIs with a single tangible element we first determine the pins with the largest distance to each other. These two points specify the position and length of the pTUI. If there is a third point, the orientation of the pTUI can be calculated as well. After detecting the pTUIs' position and orientation the content on the mobile device can be updated according to the position of the tangible component.

We follow the same technique described above if the TUI contains more than one tangible element. If multiple tangibles are in use, they can be differentiated by the layout of the brass fasteners that touch the screen. Thereby, our approach is limited by the number of touch contact the used mobile device supports. Current tablet devices typically support 10 or more touch contacts that can be sensed simultaneously. Having 10 touch contacts limits the number of tangible elements that can be sensed simultaneously to three if position and orientation are important. The approach is further limited by the fact that we cannot reliably differentiate between releasing a tangible and lifting it from the screen. Hence, we store the most recent position of each element and use this position in the web applications.

pTUI Examples

The combination of conductive paper TUIs and a web application enables to create an almost infinite number of different pTUIs. In the following, we present three pTUI examples that show the diversity of the emerging application possibilities. As we aim to increase the distribution of TUIs and to enable individuals to (partly) manufacture them by themselves, the three examples of pTUIs are made of materials that allow cheap and easy production.

Paper Pong

We implemented Pong, one of the earliest arcade video games using a combination of a tangible rackets and a web application. We use the pTUIs as tangible rackets with their position detected by two conductive pins. Here, two pins are enough as the rackets have neither a front nor a back side (cf., Figure 1 – left). The paper rackets allow the user to control a ball of the Pong app in real-time. The game itself, including the ball and the scores, are shown by the web application. This example especially shows that pTUIs can be used in highly interactive systems, such as tangible games.

Paper Urp

We rebuilt one of the earliest TUIs – Urp [7] – as a pTUI to demonstrate that paper TUIs can be used to simulate real-world contexts, like urban planing scenarios on a mobile device. As in the original Urp, wind flow and shadows of buildings are influenced by the arrangement of architecture represented by the pTUIs (cf., Figure 1 – center). The architecture blocks are again detected with conductive pins. Using pTUI for a paper version of Urp enables the end-user to simulate mobile urban planning scenarios, which was not possible with the original version from Underkoffler and Ishi. Furthermore, we envision that pTUIs are so easy to build that architects and students could be enabled to implement pTUIs as part of their daily work.

Interactive Christmas card

The interactive Christmas card used as tangible a paper Christmas manger that contains three conductible pins at the bottom. Thus, the according web application that detects the pins can, besides size and position, also detect the orientation of the manger. The web application initially shows falling snow on a snowy landscape. After

Figure 3: Examples of photos posted on Facebook by recipients of the Christmas card.

the manger has been placed on the touchscreen, an animation of the Christmas story is played exactly underneath the manger. This Christmas animation is visible inside the manger from its front through a mirror placed diagonal inside the manger similar to Broy et al. [1] (cf., Figure 1 – right). Thus, the pTUI contains a display that can show arbitrary content inside the pTUI and seen from its front side.

Distributing pTUIs in the large

To investigate the feasibility of our approach on a large scale, we aimed to distribute pTUIs to a large audience. Therefore, we used the interactive Christmas card described above as the labs' Christmas card and produced 300 entities. We optimized the building plan to fit on half an A4 sheet of thick paper. The building plan was further divided in two parts to fit into a standard envelope. Using our lab's laser-cutter enables to produces four managers with one cutting run. Before cutting we printed a texture on both sides of the thick 300g paper (the thickest paper our laser printer can handle). After printing and cutting, we filled standard envelopes with the paper manger cutout, three brass fastener (conductive pins), an aluminum band, a piece of mirror foil, and a greetings card with web links to build instructions and to the web application that makes the manger interactive.

The filled envelops weighted less than 20g, which enabled us to distribute them via mail for 0.60€ to national and 0.75€ to international recipients. We sent 300 interactive Christmas cards by mail to our group's contacts and provided an online manual with pictures of each of the nine construction steps. Five examples of these steps can be found in Figure 2.

We started to distribute the 300 Christmas cards 10 days before the 24th of December to national and international recipients. As mainly intended as a proof-of-concept we recorded with the web application visits per IP address. That indicates how many pTUIs have been built and connected with the digital content via our web application.

Two weeks after sending out the Christmas cards via mail, 114 unique users accessed the web application. The majority of the users were in Germany (57%). Other countries include the US (21%) and Great Britain (10%). Additionally, we collected photos that recipients shared on Facebook or by email (see Figure 3). As we learned from these photos and from informal feedback we got that the recipients very much liked the interactive pTUI Christmas card, and that a large number of our recipients managed to successfully build the paper manager. However, other recipients posted, for example, photos of the unfinished pTUI typically joking about the trickiness to build it. Another recipient posted a photo of a creative interpretation of what he was intended to build. Some recipients expected to be successful but as their photo proved they did not receive the animation underneath the manger. These examples highlight how important it is to design the building itself but also the instruction in a way that it is extremely easy to use. However, most recipients posted or sent photos of videos that showed the pTUI in action. While the preliminary results are likely biased as recipients that were successful are more likely to share the result we still consider the overall feedback as very promising.

Conclusion and Future Work

In this paper we introduce pTUIs – cheap, mass-producible, tangible user interfaces made out of paper, brass fasteners, a metal band, a web application, and in dependance of the context additional material,

such as a mirror foil. pTUIs can be recognized by state of the art capacitive touchscreens which enables to use them as tangible game controller, to display specific information around their placement, and to even display information inside them using mirror foil. We showcased three different pTUIs to highlight the flexibility of the approach. In addition, we describe the pTUI distribution into the large through sending the tangible components via mail and providing the recipients with an web application to access the digital part of pTUI, which in combination results in paper tangibles that users can interact with using their mobile devices.

We sent interactive pTUI Christmas cards to 300 recipients and received initial feedback. We conclude that pTUIs are promising means to distribute and study TUIs. However, not all recipients successfully constructed the pTUI they received, which highlights the importance of a usable design and instruction manual. We are mainly interested in distributing further examples of pTUIs into the large to enable an analysis of the interaction with pTUIs in the large. At the moment pTUIs must be touched by the user to be recognized by the touchscreen. It is not possible to reliably detect if the tangible is lifted from the screen. Therefore, we are interested in adopting the approach described by Voelker et al. in future work to recognize the tangible elements without been touched by the user [8].

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