A Pen-Centric System to Support the Design Process on Tangible Media

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ABSTRACT

During architectural and industrial design processes, designers interact with a mixture of digital and physical media using a pen as an input device. While pens are the most common instrument used across different phases of the design process, their interaction on physical media is limited and difficult to transfer to the digital world.

In this thesis, I propose to facilitate the use of a pen in the design process by extending the pen's capability to not only write, but also to capture, interpret and transfer data. To that end, I built two pen-based systems: ModelCraft and PenLight. ModelCraft uses a digital pen to assist the initial review phases of design by capturing modifications made on surfaces of physical models and updating corresponding digital models. PenLight simulates a miniature projector mounted on a pen to dynamically overlay digital information on top of a paper surface. Using PenLight, users can combine digital and physical data into a single view for review and survey in the late stages of design.

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General terms: Design, Human Factors

Keywords: Digital pen, rapid prototyping, mobile projector

INTRODUCTION

Pen input has been closely tied to the conventional architectural and industrial design process from brainstorming to the refinement stage. Designers draw on the back of a napkin when an idea strikes; they edit large blueprints; and they share written annotations among different coworkers. Although a fully digital design process has long been advocated, designers still opt to use physical media such as paper due to its unique affordances [13]. As designers iterate between these two different representations during their work cycle, reducing the overhead of switching back and forth between digital and physical representations will improve their workflow. Because of the ubiquity of pens, I improve upon the pen as input device for seamless transitions between the physical world and the digital world.

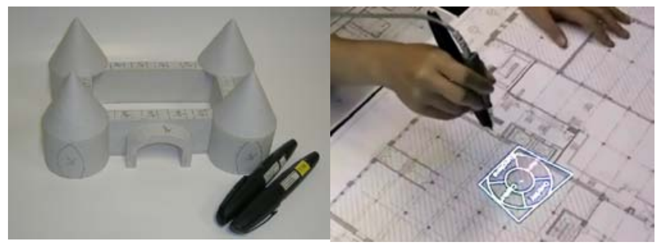

Figure 1 (a) The ModelCraft system can capture annotations and edit marks on the surface of 3D models.(b) PenLight system dynamically overlays digital information on top of a physical printout.

Researchers have built systems to pursue this goal of bridging the digital and physical. Digital Desk [19] and Ariel [11] augment paper documents with spatially-overlaid digital content by using overhead projectors. A-Book [12] lets users manage the missing relational information between paper, physical artifacts, and on-line data.

Recently, the Anoto-pattern based digital pens [2], which contain a miniature camera, are used to improve usages of pen and paper. This pen presents several unique characteristics. Hardly any calibration is required. It is scalable in terms of the amount of paper and number of pens that can be used simultaneously. These properties allow researchers to explore interactive paper interfaces in mobile computing environment. PapierCraft [8] describes how gestures made on paper can be interpreted as digital commands to facilitate transferring physical annotations to the digital world. between physical . PaperPoint [14] illustrates how physical pen and paper can be used as a computer input device. ButterflyNet [20] demonstrates how Anoto pattern paper and the digital pen can benefit field biologists.

The two systems that I built, ModelCraft [15] and PenLight [17], utilize same pen technology to bridge the gap between the physical and digital worlds in architectural domain. ModelCraft (Figure 1a) tries to bridge the gap between the physical models and digital models by automatically capturing annotations and edit marks on the surface. On the other hand, PenLight (Figure 1b) enhances the visual feedback

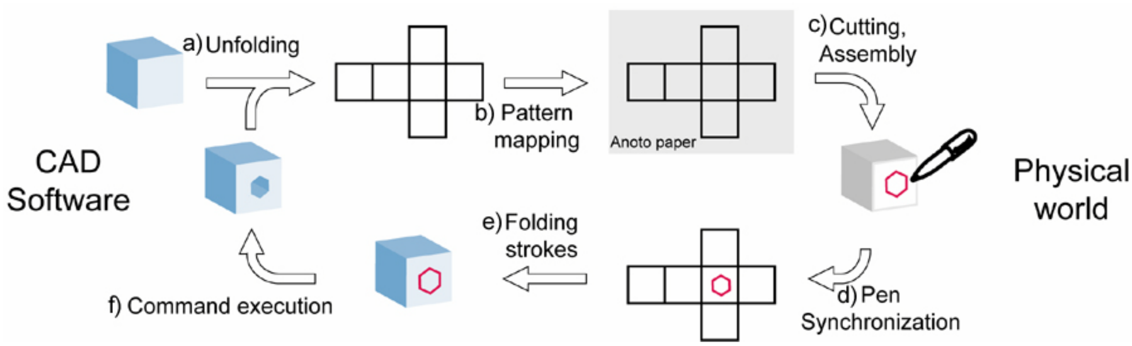

Figure 2: Life cycle of a model produced by ModelCraft

available in a digital pen to bring digital functionalities to the domain of physical paper.

PRELIMINARY RESULTS

I explored two sub-areas of digital pen computing, *capturing pen-input for non-digital 3D surfaces (ModelCraft)* and *using a mobile projector as a pen-top feedback (PenLight),* for my target audience: architects and designers.

ModelCraft: Capturing Freehand Annotations and Edits on 3D Models

Interacting with 3D physical models is an intrinsic part of the architectural design process for aesthetic and structural tasks. Physical models offer a unique presence that is difficult to reproduce on a screen. Hence, projects that rely heavily on computer-assisted design techniques still employ tangible models in different phases of design such as brainstorming. Frequently, sketches that describe the modification and edits to be made are drawn on the surface of the model. With most of current techniques, information described in this way on such models is difficult to integrate back into the digital world.

While annotations made on the surface of 3D models can be captured by a conventional tracking system (either magnetic or optical) as proposed by Agrawala et al. [1], that approach is limited to a relatively small working volume, requires significant investment in infrastructure and a calibration process on a per-model basis, and is somewhat expensive. It is also difficult to deploy in the field where models are frequently tested. This limits widespread adoption by architects and designers.

To address this issue, I proposed the ModelCraft framework [15, 18]. ModelCraft provides an off-the-shelf digital pen (Logitech io2™ pen [10]) to capture annotations and edits on the surface of physical models. ModelCraft is an extension of the SolidWorks CAD program that helps users create a traceable 3D model from a virtual model (Figure 2). When user creates strokes using digital pens on physical models, it is captured and transfers back to the original virtual 3D model.

Users can produce traceable 3D models by printing (Figure 2a) the 2D layout of a 3D model on top of one or more sheets of Anoto pattern [2] paper (Figure 2b). ModelCraft is scalable in terms of the number of traceable physical models because each uniquely-identifiable page can be mapped to different models using the PADD infrastructure [5]. If different pattern space is used for two identical virtual models, interactions on the same virtual model can be managed independently.

The pen not only captures annotations but can also be used to capture edit commands to be executed directly on the digital CAD models. Our objective is not to replace the standard (and far more accurate) CAD construction process, but instead to address two disparate needs. First, in the early stages of design, a rough prototype is often sufficient to present or verify a designer's idea. For instance, if after 3D printing it is found that a piece conflicts with another element in the design, simply marking the conflicting area and cutting it away may be all that is needed. Second, we found that when a large number of marks are made on the prototype, it is somewhat difficult upon review to understand how the marks relate to each other. In that context, providing tentative feedback to the executed operations helps the users to understand the structure of the marks.

All commands follow a uniform syntax (Figure 3) inspired by Scriboli [6] and PapierCraft [8]. To issue a command, users first draw the necessary parameters directly on the surface of the model (Figure 3a). Next, they draw a pigtail gesture, which is used as a separator between the parameter strokes and the command identifier (Figure 3b). Next, they indicate which command they wish to execute by drawing a

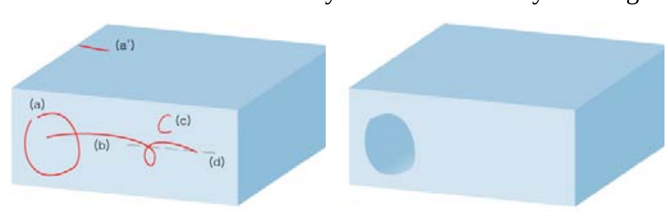

Figure 3 Command syntax for editing a single object. **Left:** (a) main parameter; (a') additional parameter (in this case, the depth of the cut); (b) pigtail delimiter; (c) command name; (d) reference line for character recognition. **Right:** the result of command execution.

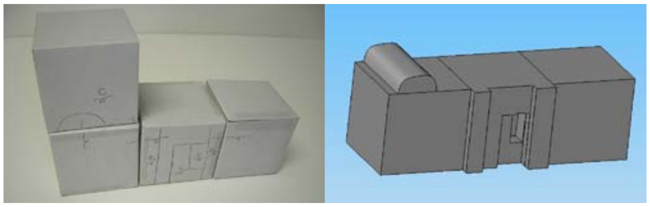

Figure 4: Assembly Feature. Stitching gestures can be used to define how models should be connected.

letter or a simple word on top of the pigtail (Figure 3c). During pen synchronization, the command is then executed using the area on which the pigtail started as the primary shape parameter.

User Evaluations

The ModelCraft system [15] has been through series of evaluations and expert interviews with professional architects and architecture faculty.

Several architects pointed out that our system would be perfect for bridging the gap between the physical and virtual modeling processes in architectural design, and in particular, massing a building. During massing, new physical models are built based on marks or shapes that were suggested in the previous iterative cycle. This type of practice is well suited for the ModelCraft interactions. Architects further pointed out that annotations on paper models could be useful for capturing feedback from some of their clients who might be intimidated by digital models. They also commented that the support for “free space” sketching by using information sketched on extra papers will be useful. This feedback motivated the idea of adding a paper protractor and paper sketchpad in the extended version of our system ([18]). They also mentioned that operations involving multiple objects are very useful in early design because architects often create new designs by stacking or joining available building blocks, which was another feature we later added to ModelCraft (Figure 4).

One of the architecture students pointed out that the system would be very useful for teaching and would support current practices taught at school. The professor remarked that our system would allow students to explore prototyping and develop 3D thinking skills, because visualizing the 3D results of subtractive operations drawn on a face of a cube is a common task in architecture training. This discussion led to a formal user study during an introductory architecture class at the University of Maryland using a simplified ModelCraft system called CubeExplorer [16]. From the formal study we were able to conclude that ModelCraft creates a natural bridge between the traditional approach to architecture (based mostly on paper-based sketching) and the use of modern applications such as SketchUp [4].

For the evaluation of CubeExplorer [16], many feedback mechanisms had to be implemented. Earlier version of ModelCraft synchronized the digital pen with a computer only in batch. However, the professor of the studio wanted to use the system with instant feedback. As first feedback mechanism, we provided an LCD display that indicated the result of operations. Secondly, as users also wanted feedback on which stroke to execute, audio feedback indicated which syntax came after the current stroke. These supplemental instrumentations extend the function of digital pens from merely a capturing tool to a complex computing device.

PenLight: Mobile Projector and a Digital Pen

As a matter of fact, the most recent improvements in digital pen technology have been focused in novel feedback mechanisms to support diverse digital pen applications [3]. Haptic vibration and audio feedback were provided by the first generation of digital pens [21]. Liao et al. presented a guideline matrix [7] to describe whether to choose color LEDs, tactile feedback, or audio feedback to improve the accuracy and the error rate of the interactive paper interface. Recently, LiveScribe [9] embedded an 8 by 20 millimeter LCD display into the barrel of a digital pen to display the result of computations based on pen input. This has enabled commercial applications such as displaying a translation of input text. I believe that richer forms of visual feedback such as a pen-mounted projector will be available in the near future. However, such form has not yet been explored.

To explore this design space, PenLight [17] simulates a spatially–aware digital pen with a miniature projector. The combined pen and projector captures the 3D location of the pen tip on or above the paper surface and overlays images on the paper. This new hardware design introduces a unique interaction design space and accompanying interaction techniques.

Interaction Design Space: Virtual Display Layer

By simulating the concept of a digital pen combined with a miniature projector, we were able to identify how pen input made on the surface or above the paper can be interpreted to manage several virtual display layers:

- UI layer: By moving the pen on and above the paper surface, the user can make a menu selection (Figure 1b).

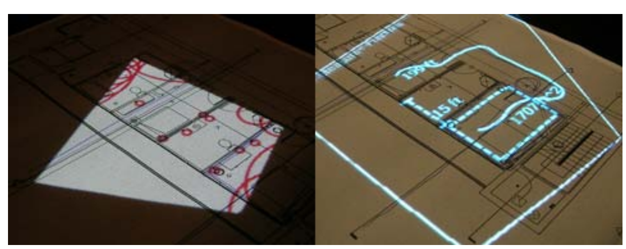

Figure 5: PenLight **Left:** Users can locate icons on a printed document using pen input with the Halo technique. **Right:** Users can execute computations by inking on the surface and then augmenting the virtual result.

- Ink layer: User can store the virtual ink created on the surface of the printout in the virtual display layers. For example, if a user wants to execute computation based on a sketch, the computed result can also be stored in the virtual layer then augmented on the paper. (Figure 5, Right). This ink layer can also be useful between remote collaborators by supporting illustrative communication. Using a second Anoto pen, and printing out a second copy of a floor plan, annotations made by one user can be displayed in real time as virtual ink on another user copy of the floor plan.
- Content layer: The user can overlay or displace virtual contents that are relevant to the printed content underneath. For example, users can search for the entire power outlets printed on the map (Figure 5, Left).

FUTURE WORK

PenLight simulates a miniature integrated projector, instead of a separate pen and a projector, because we wanted to support mobile usage scenarios where fewer and more-lightweight hardware components are preferred. However, to fully explore the potential of visual feedback in digital computing, other possible hardware configurations should be compared to PenLight. For example, a separate projector can be provided for digital pen applications. Furthermore, visual feedback mechanisms other than projectors exist as well. If the content of interest can be displayed separately from the physical printout, a PDA screen can suffice. I plan to survey interactive paper interfaces in different visual feedback scenarios. This will outline and clarify the hardware design space of visual feedback-enhanced digital pens.

CONCLUSION

I believe that the computing devices of the future, such as digital pens, will enhance the experience of designers by reducing the gap between the digital interactions and the physical interactions. Using a digital pen, design related information can be intelligently updated from the physical space to the digital space (ModelCraft). A digital pen combined with a visual feedback can coordinate information from digital domain to the physical domain (PenLight). My future work continues on providing a pen-centric framework to support the design process on tangible media.

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