INKTUITIVE: AN INTUITIVE PHYSICAL DESIGN WORKSPACE

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Abstract

The development of computer-aided design (CAD) tools such as Autodesk Revit, ArchiCad and SketchUp, has leveraged the power of the digital world by allowing designers to express their creations in new ways. Despite the advances and advantages of these digital tools, traditional pencil and paper continue to exist as some of the most important tools in the early stages of design. In this paper, we introduce 'Inktuitive', an intuitive physical design workspace that aims to bridge the gap and bring together the conventional design tools such as paper and pencil with the power and convenience of the digital tools for design. The paper discusses the design and implementation of the 'Inktuitive' platform. The paper also analyzes and outlines the advantages and challenges of this new workspace, where designers can create and manipulate digital models and representations of ideas in a more direct and natural way.

1 Introduction

Recently, a new design paradigm is emerging in the field of computer-aided architectural design. As opposed to the conventional method of drawing primitives on multiple 2-dimensional floor plans, it is becoming increasingly popular to directly model 3-dimensional representations of the actual component objects being used and to specify the relationships between them parametrically to design an architectural product. CAD tools such as Autodesk Revit, ArchiCad and SketchUp are examples of tools that support this new paradigm known as Building Information Modeling (BIM) [2]. This new design paradigm allows for the design changes to be made simpler allowing CAD tools to be used at various stages of the design process from the abstract, conceptual design phase, where flexibility to try out multiple what-if scenarios is essential, to the construction detailed design phase, where consistency and accuracy carry more weight.

On the other hand, in spite all the advancement in computer-based design tools, many architects still prefer to use physical tools such as paper and pen to articulate their ideas especially in early stages of the design, where it is critical that your hand-motions have direct and immediate effect on the object being designed. As the new design paradigm proliferates, challenges in adopting such affordances of physical design tools into the digital realm become of increased importance. In addition, as architects start thinking in terms of 3-dimensional objects rather than in 2-dimensional floor plans, a new set of interactions that augments the conventional use of pen/pencil on paper needs to be sought. Instead of replacing the traditional tools, paper and pencil, it will be more fruitful to merge the advantages and functionalities of digital design tools with traditional work practice of using paper and pen, hence connecting the physical and digital experiences.

The purpose of 'Inktuitive' is to create a workspace that has the advantages of both the physical and digital design tools. The intuition of pen and paper are still present, but lines are be captured and translated into shapes in the digital world. The physical paper is augmented with overlaid digital strokes. Furthermore, the platform provides a novel interaction mechanism for drawing and designing using above-the-surface pen movements.

2 Related Work

There are many projects aiming to create a relationship between physical and digital workspaces. The DigitalDesk [4, 7] provides an environment in which physical paper gains electronic properties, while physical objects can be used to operate electronic documents. There are also systems, such as LivePaper [6], that add digital information to enrich the interaction with physical artifacts like paper. Many research projects have specifically attempted to support architects and designers within the early stages of the design process. Electronic Paper [1] explores augmented reality based approaches for supporting early stages of design. Luminous Table [3] combines and integrates two dimensional drawings, physical models and digital models to support the urban design process. On the other side applications such as SKETCHPAD+ [5], focus on creating 3D scenes in a natural and intuitive way on systems that only offer 2D interactions.

3 INKTUITIVE

3.1 What is Inktuitive?

Inktuitive is an intuitive physical design workspace. The goal of Inktuitive is to combine the intuitive process of creation that is inherent in paper and pencil with the power of computing that digital design tools provide. Inktuitive also extends the natural work-practice of using physical paper by giving the pen the ability to control the design in physical three-dimensional space, freeing it from its tie to the paper. The platform brings enormous advantages of digital design tools to traditional and natural work practice of designing. The following use scenario outlines major features of the 'Inktuitive' platform.

The designer first draws an outline of the building foundation on the paper. In parallel, the drawing is digitally captured and turned into a 2D polygonal object in the digital realm. The orthogonally projected image of the polygon is then displayed (as a line at this point) on the vertical LCD screen along with other supportive views. Now the user can lift the pen above the paper to specify the height of the building. The corresponding change in the vertical screen occurs as the pen is lifted up or down (the original line changes to rectangles of different sizes). The user can change the viewpoint using the multi-directional controller knob. As the viewpoint is changed, the drawn object rotates on the LCD screen. At the same time, the overlaid copy of the drawing on the paper shows up as digital augmentation and starts deviating from its original physical ink location to match the selected viewpoint. Now, the designer can start drawing relative to the digitally displayed objects on the paper surface. For example, windows can be drawn on walls or an extension to the building can be extruded out of the walls using above the paper pen movements.

The above-the-surface pen motion can also be effectively used on manipulating curved surfaces of the building. For example, the pen tip can be assigned to a control point of a parameterized surface such as roof tops. The user can manipulate the control points in the air with one hand

Figure 1. Inktuitive system design

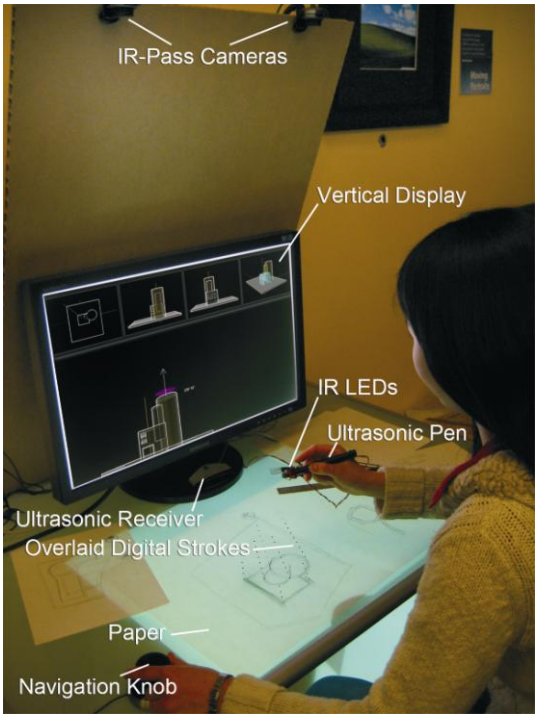

Figure 2. 'Inktuitive' prototype

while with the other hand use the multi-directional knob. Besides designing by creating and manipulating 3D geometry using an object based design method, Inktuitive platform can also be used to study the effects of light or wind and its impact upon the designed objects.

3.2 How does 'Inktuitive' work?

Figure 1 presents an explanation on how 'Inktuitive' works. The 'Inktuitive' system provides a physical workspace environment where digital content is projected from below onto the paper placed over the frosted-glass surface of the desk. Pen movement on the surface of the paper is tracked by ultra-sonic digital-pen hardware. Two stationary sensors receive ultra-sonic waves that are emitted by the transmitter placed at the tip of the pen. The device measures the location of the pen tip on the paper using the calculation of receiving time of the waves received by the two stationary receivers. Further, the pen tip is also augmented with infra-red (IR) LED array for tracking the three-dimensional coordinates of the pen above the paper surface using stereo vision. Two USB cameras with IR-pass filters mounted above the table detect the IR light emitted by the LEDs which are used to calculate the three-dimensional coordinate of the pen tip via triangulation. The projector, ultra-sonic pen hardware, cameras and SpaceNavigator are all connected to a PC. A software program processes the data collected by the digital-pen hardware and two cameras. Image processing of the two camera inputs provides the system with absolute location of the pen tip in three-dimensional space above the paper surface while the ultra-sonic components help capturing precise user strokes on the paper surface. The software program uses these two streams of user hand motion in augmenting the paper on the desk with projected digital information.

3.3 Implementation

We have developed a working prototype of 'Inktuitive' as shown in figure 2. The prototype consists of a projector-based table-top work surface, a vertical LCD screen, Pegasus NoteTaker ultra-sonic digital pen device, two Microsoft LifeCam VX-3000 USB cameras, 3Dconnexion SpaceNavigator 3D mouse and a PC. The projector displays the graphical contents from below and augments the paper placed on the desk with digital information. The vertical LCD screen is used to provide the supplementary graphical information. The ultrasonic digital pen is augmented by an array of IR LEDs at the tip of the pen. The pen is used to capture the stroke on the paper as well as gestural input device in three-dimension above the surface of the paper. The images from USB cameras are captured in VGA resolution (640x480) at 10 frames per second via the Microsoft DirectShow interface. The images are used to calculate centroidal pixel coordinates of the IR LEDs using OpenCV (see Figure 3.) Three-point averaging in time domain is performed to achieve smoother tracking. They are then used to extract depth information using the following equation.

$$D = f / dx$$

where f is the focal length (number of pixels the unit-length object occupies at unit length away from the camera) and dx is the disparity in the x coordinates of the centroid calculated from the two images. This depth information corresponds to the Z coordinate of pen tip in camera coordinates. This data is rotated and scaled by reference data acquired through 5-point calibration (4 corners of the horizontal work surface plus a point at maximum height) to extract the three-dimensional location of the pen tip in coordinate system with the origin at the lower left corner of the work space on the desk. In addition to these, the system also uses the SpaceNavigator 3D mouse for rotating, zooming and navigation in the design space. The software is built upon .NET platform using C# and C++. Google SketchUp API and SDK are used to create the digital drawing interface.

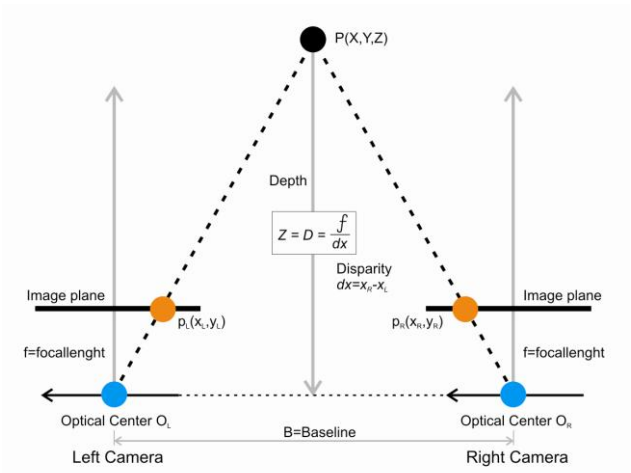

Figure 3. Stereo vision mechanism for detecting pen coordinates above the surface.

4 Future work and Discussions

A unique property of Inktuitive is that allows the architect to use pen-motions in the workspace above the paper to capture their ideas. By freeing the pen from its bond with the paper, Inktuitive allows the architect to draw windows on the vertical planes of their buildings, change the height of a building through vertical hand movements, etc. The fact that the changes on 3D objects occur in direct relation to the spatial hand motion will give the user more intuitive control over the object or the control points on parameterized objects as if she is grabbing it within the actual physical volumetric space formed by the two orthogonally placed displays. This together with the expressiveness of sketching on paper gives designer more freedom to explore their design possibilities focusing on the design itself rather than wasting their valuable attention on extra control manoeuvres like menu selection. It also allows the user to edit objects or control points while changing the views to see its effect from different angles on a single screen. For example if the user is editing the curvature of a roof top on a building, the user can specify the location, a 3D control point, with one hand while, zooming or rotating the camera point around the control point with the other hand. This kind of interaction conventionally requires two screens, one for editing and one for viewing because the mapping of 2D mouse motion into 3D motion generally gets destroyed as the viewpoint is rotated. The fact that the changes on 3D objects occur in direct relation to the spatial hand motion also supports collaboration since the non-operating person can easily see what the designer is currently trying to do. The system currently supports single user input but should be easily expandable to support multiple users and multiple pens.

One limitation of working above the surface is the loss of pointing accuracy because human hands tend to be a lot less accurate in free space without a reference surface. This inaccuracy may be tolerable in many cases where the designer is trying to roughly model their initial ideas. In other cases, views can be rotated so editing can occur on the solid surface as conventionally done or alternatively supporting stencils such as vertical rulers may be used in combination.

Current scope of Inktuitive is targeted to architects in their early stage of design. We plan to extend the scope of 'Inktuitive' as a platform for designing for product designers, set designers and other work practices that involve designing physical space or objects. We are in process of evaluating the proposed new interaction mechanism through a qualitative user-study. We also plan to report the user-study results in near future.

5 Conclusion

In this paper, we present 'Inktuitive', an intuitive physical design workspace which brings the power of computing and digital design tools to the traditional work practice for designing using paper and pencil. We explain the design and implementation of the working prototype of

'Inktuitive'. At the end of the paper, we also discuss some advantages and challenges of the proposed new interaction mechanism.

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