

***i-m-Top*: An Interactive Multi-Resolution Tabletop System Accommodating to Multi-Resolution Human Vision**

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Abstract

*For human vision, the resolution of visual perception is not uniform across the entire eye, in which the fovea, a dimple on the central retina, provides our highest resolution vision. While many researchers have focused on building a large homogeneous high-resolution display for better visual quality, our approach goes a step further to exploit the variable-resolution nature of human vision on tabletop systems. In this work, we developed an innovative tabletop display system, called *i-m-Top* (interactive multi-resolution tabletop), featuring not only multi-touch, but also multi-resolution display accommodating to the multi-resolution characteristics of human vision. Based on this characteristic, *i-m-Top* provides a high-resolution projection image in the foveal region with a steerable projector, while providing a low-resolution projection image in the peripheral region with a wide-angle fixed projector. With this configuration, we are able to realize an interactive high-resolution display in a cost-effective way. To hide the engineering challenges posed by the unique hardware configuration, we also develop a software development toolkit – the *i-m-Top SDK* – for rapid prototyping multi-resolution and multi-touch applications, to help push forward research in this field.*

1. Introduction

Researchers had studied the spatial variation in human visual resolution[8]. Their studies showed that only the foveal region near the gaze point of human eyes can afford sharp vision with acute visual details. This spatial variation in human perception has been widely exploited in many applications, including level-of-detail rendering, video compression and information visualization[7], in reducing display resolution outside the region of interest, to lower the amount of computation and economize system cost.

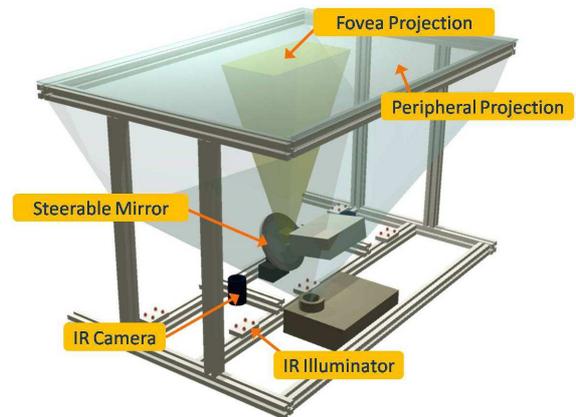


Figure 1. The hardware architecture of the *i-m-Top* system. The multi-resolution display is integrally provided by foveal and the peripheral projections.

The construction of displays can also take advantage of the multi-resolution characteristic. Typically a large-sized high-resolution display is built by tiling up projectors or LCD screens, with which deployment considerable cost and space are required, and tedious installation is inevitable. To this situation, the multi-resolution characteristic provides a cost-effective solution, especially when a personal-use scenario is targeted. In *Escritoire*[1], a front-projection multi-resolution table system is proposed, in which the high resolution projection is arranged in the center area of the tabletop while low resolution projection for the rest. By integrating a projector and a LCD screen, *Focus Plus Context Screen*[2] is a multi-resolution display standing on the table. Their work conducted a series of studies evaluating such setup affords well in many real world tasks. For the two works, the displays are for personal use and the high resolution area of the display is fixed.

Our vision of a multi-resolution tabletop system includes a fixed and a movable projections for the full tabletop and a sub-region respectively, and an eye tracker that monitors the user's staring. The movable projection provides just-in-time resolution enhancement at the region of user's interest on the tabletop inferred by eye tracker and user's gestures. Targeting a personal work desktop, a movable projection is enough. However, with the trend of small form factor projectors, multiple high resolution projections can be included and thus to support multi-user scenarios.

In this work, we developed a rear-projection tabletop display system, called *i-m-Top* (interactive multi-resolution tabletop), featuring not only multi-touch, but also multi-resolution display (see Fig 1.). *i-m-Top* provides a high-resolution projection image in the foveal region with a steerable projector, while providing a low-resolution projection image in the peripheral region with a wide-angle fixed projector. To hide the engineering challenges posed by the unique hardware configuration, we also develop a software development toolkit, the *i-m-Top* SDK, for rapid prototyping multi-resolution and multi-touch applications.

2. Related Work

To build a multi-resolution display, *Escritoire*[1] and *Focus Plus Context Screen*[2] introduce a high-resolution area fixed in the center of the display upon a table setup. In the *Fovea-Tablett*[6], multiple tablet PCs (tablets) are used as high-resolution regions on a tabletop system. With visual markers attached, the positions of the tablets are tracked and the displayed contents on the screens are at high resolution. Considering tablets as tangible exploration tools, *Fovea-Tablett* is well suited for multiple-users tasks, but there would be a physical boundary, the edges of the tablets, between high and low-resolution displays. In contrast, our system provides a movable high-resolution projection by using a steerable projector. The resultant display is seamless, and the high-resolution projection can be guided by users actions such as eye gazing and gestures, leading to richer interactions. Another scenario on multi-resolution displays created by multiple handheld projectors is included in [3], where the multi-resolution display is achieved by two handheld projectors held by two users. One projector is held afar to create the low-resolution display in a larger area, and another projector close to the surface creating a high-resolution focus region within that area. As the poses of projectors in use are tracked, their approach provides flexibility in that users can dynamically move the projectors to create multi-resolution display in different sizes and resolution combinations.

Other works addressed on software solutions to help investigate new hardware setups not currently supported by the underlying operating systems. The *DiamondTouch*

SDK[5] released by MERL provides supports for developing multi-touch applications on *DiamondTouch*, to facilitate investigations of computer supported collaboration and interactions. *DiamondSpin* [9] presented a java-based toolkit with a real-time polar to Cartesian transformation engine for fast prototyping around-the-table interactions. To construct a high-resolution multi-user tabletop applications, *T3*[10] provides an API to stitch multiple projections into a single display for co-located and remote collaborators, and also common user interface components for fast creation of complex applications. As *T3* can also apply to build a multi-resolution tabletop by stitching up foveal and peripheral projectors together as a single display, our SDK instead is devised thinking the tabletop more of a multi-resolution one, and thus to help designers creating multi-resolution embedded user interfaces and interactions.

3 The *i-m-Top* System

The display of *i-m-Top* composes of two DLP projectors, the foveal projector and the peripheral projector, as shown in Fig.1. The projection of the foveal projector is first reflected by a steerable mirror to illuminate a particular region of the tabletop. The foveal projector, when projecting toward the center region of the tabletop, is able to cover a region of 11.6 inches wide by 7.5 inches high with 1,280 x 720 pixels, yielding a resolution of 110 x 96 ppi on the region. The resultant resolution is equal to that afforded by a 17-inch LCD screen with 1280 x 768 pixels. The peripheral projector with a wide angle lens (at 0.6m could fill 1.0m screen) provides a full coverage of the tabletop (47 x 32 inches), yielding a resolution of 27 x 23 ppi. If the same resolution of the foveal region is required for the full surface, a projection of at least 5170 x 3072 pixels is required, or else, more than 16 projectors should be tiled. The steerable mirror is controllable of position, speed and acceleration via RS-232; the speed is over 300 degrees/sec and the resolution is about .0514 degrees, which are sufficient for developing real-time interaction.

The approach for touch-sensing on *i-m-Top* is based on a diffused illumination setup. We set two wide angle infra-red cameras and several infra-red illuminators for multi-touch detection. A fingertip finding algorithm proposed in [4] is applied. The algorithm works with a diffused illumination setup to recognize reflections left by the fingertips when users hands touching the tabletop. For more details of the algorithm can be found in the paper.

4 The *i-m-Top* SDK

In this section, we introduce the *i-m-Top* SDK, including the design goals and concerns for the implementation.

4.1 Design Goals

Hide engineering details Constructing a multi-resolution display requires prerequisite knowledge of geometric calibration. Not only the tedious installation and calibrations are inevitable during the system configuring phase, but once the system accomplished, the designer needs to write abundant codes in order to initiate a simple application. Unlike other applications, writing a multi-resolution one involves different concerns. Firstly, a memory-intensive situation should be handled in order to take advantages on the power of high resolution display. For a better use of memory, an object shall only load its high resolution content on entering the foveal region, and unload it on exiting. Secondly, the overlapped region on the low resolution projection should be masked out to avoid ghost artifacts from double projections. Thirdly, when the foveal region is movable, more steps are introduced at each move: switching to homography of current foveal projection, loading and unloading high-resolution images, masking out overlapped areas on low resolution projection. Most of the troubling but essential steps can be done automatically by our SDK, the designer therefore can face directly to the interface and interaction design.

Use of a metaphor To help the designers quickly understand the operations of multi-resolution, the spotlight metaphor is introduced into the naming of SDK functions. In the SDK, the tabletop given by peripheral projection is regarded as a stage. Enhancing a particular region of the tabletop by foveal projection is analogous to spotlight the region. Spotlight provides good cognitive affordance for programmers/designers realizing the role of foveal and peripheral projections. To build a multi-resolution application, the user needs to create a stage object and a spotlight object which correlates to the two projections respectively. On the calibration phase, the spotlight object has to be calibrated with respect to the stage, in order to define a movable area of the spotlight comprising of multiple poses of the foveal projection. On the design phase, the user initiates the spotlight by loading its configuration file and mounting the spotlight to the stage. The SDK provides functions including: to shift the spotlight, to turn on/off the spotlight, to retrieve objects inside/outside the spotlight, or to place an object on the spotlight.

Extensibility The SDK provides general IO interface which facilitates data transmission via UDP, RS232 and window message. A finger-touch receiver is provided by the SDK upon the general IO interface, which receives fingertip information obtained from finger-touch detection and dispatches finger-touch events to the application. Based on the

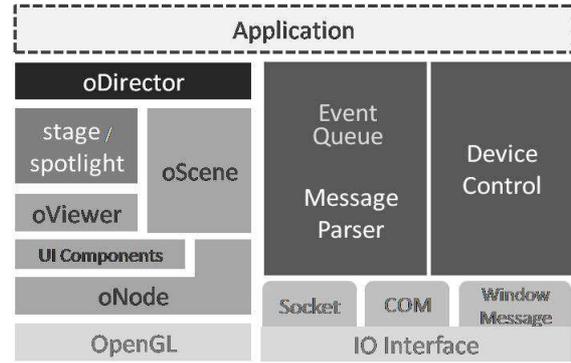


Figure 2. The diagram of the i-m-Top SDK.

interface, additional sensors can be easily integrated with the SDK.

4.2 Implementation

Objects in real world such as director, viewer, scene and node are used in the SDK, as shown in Fig.2. The director is responsible for communicating with the scenes and the viewers. The scene is where the virtual world created. The viewers are virtual cameras with different poses looking at the scene to obtain rendered images for projections. In a multi-resolution application, the foveal projector and peripheral projector are two viewers of the scene, recognizing as spotlight and stage objects directly controlled by the director. To achieve the real-time requirement, the i-m-Top SDK takes advantages of hardware acceleration supported by OpenGL. We use Stencil buffer to mask out double projections, and adapt the rendering pipeline to pre-warp the skewed projections by multiplying homography to the projection matrix. For rapid prototyping complex applications, the SDK supports basic multimedia inputs including camera capturing, audio and video processing, as well as user interface components such as button, scrollbar, virtual keyboard and textbox. For downloading the SDK can be reached on <http://ivlab.csie.ntu.edu.tw/research/i-m-Top>.

5 Applications

In this section, we introduce two applications built on the i-m-Top system. These applications are developed upon the i-m-Top SDK to demonstrate the potential user interactions for a multi-resolution tabletop system.

The Google Map Browser This application features a multi-resolution map browsing. The users can move, zoom-in/out the map by their fingers. In this application, we request maps from Google Map website on the fly. With

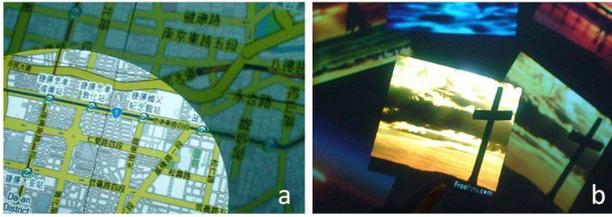


Figure 3. Two sample multi-resolution applications built on the i-m-Top SDK. (a)The Google Map Browser and (b)The Photo Browser.

the high resolution capability, the foveal region will request more detailed map images from the website to stitch a higher resolution map image along with more detailed geographic information attached on. All download map images are kept in a hierarchical structure in the memory or in the disk to optimize the system response. When the user places multiple fingers firmly on the tabletop, after a dwell time the foveal projection will move to a position best covering the fingertips. When the user activates zoom-in at a position of the peripheral projection, the foveal projection will automatically move to the same position to meet the users attention.

The Photo Browser This application features a multi-resolution photo browser. Unlike the map browser, the photo browser application has amount of photos as spotlight candidates spread out on the tabletop. The foveal projection can either use object-spotlight strategy which enhances interested photos only, or a region-spotlight strategy which enhances a specified region. With object-spotlight strategy, the masking is customized dynamically on both the foveal and peripheral projections to enhance the selected photos only. Because image objects and basic functions such as moving, scaling and rotation image objects by fingers are supported by our SDK, the photo browser can be easily realized by a novice by writing a few lines of code to create image objects and specify their locations in the table space.

6 Conclusion

This paper presents a multi-resolution tabletop system, called *i-m-Top*, and a software development toolkit (SDK) for rapid prototyping the kind of systems and applications. We have implemented the SDK, adhering to three design goals, and demonstrated potential user interactions for a multi-resolution display in two applications. User interface and interaction design for the kind of system are interesting but rarely investigated. We believe the proposed SDK is able to help push forward research in this field.

In the future, we consider the eye-tracker and user gesture recognition can work cooperatively to create natural user interactions for multi-resolution systems. We would like to explore multiple high-resolution projections working simultaneously on the tabletop system, and the potential for multi-user collaboration. Currently the regions of high and low resolution are non-overlapped specified by a binary mask. A seamless blending of the two regions can be further achieved when the displayed content is considered.

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