

Towards a Natural Interaction for Rapid Prototyping of Parametric Closets

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Abstract: Custom closets customers usually lack the expertise to design their desired closet. The use of a software tool that incorporates the design expertise might allow them to sketch their ideas without third party oversight. While architecture related applications are very powerful and make it possible to have an accurate graphical representation of real world, these Computer-Aided Design (CAD) tools demand high technical training and their use in the engineering field is generic. Our work, framed within the development of a rapid prototyping tool of custom closets called *Sketch Arm*, introduces an interaction proposal that seeks to minimize the time and complexity associated with typical operations in CAD. Supported by multi-touch capabilities of today's mobile devices, our system allows users to manipulate the closet structure directly in real time by using a minimalist graphical user interface (GUI) together with a touch interface based on easily recognizable gesture patterns. Direct on-screen data manipulation is very attractive to the end-user in general and highly beneficial for novice IT users in particular while gesture-based interaction is extremely intuitive for performing artistic tasks. Throughout the article, we will describe in depth the designed interaction system and we will present the original solutions we made to common problems in touch systems like accuracy and occlusion.

1 INTRODUCTION

Custom closets manufacturing arises in response to the spatial limitations that nowadays many of the existing housing present, improving the organization and use of available space in living quarters.

The customer usually lacks the expertise to deal with the design process independently and is assisted by the manufacturer for the creation of an initial prototype together. This model is time consuming and involves a significant increase in the final manufacturing cost. The use of a software tool that incorporates the design expertise, will allow the user to sketch his ideas without third party oversight.

To that end, there are many computer applications that facilitate the design process, enabling us to obtain a graphical representation of the real world. These Computer-Aided Design (CAD) tools, although very powerful, demand high technical training and their use in the engineering field is generic.

To address those issues, we have developed a rapid prototyping application for designing custom closets, named *Sketch Arm*. The main purpose of the system is to facilitate the operations involved in the creative

process. We propose a direct interaction system that, supported by multi-touch capabilities of current mobile devices, allows the user to manipulate the closet structure in real time, combining the use of a common graphical user interface (GUI) with the use of a gesture-based natural interface.

Touching and manipulating data directly on the screen, without using any additional input device, is very attractive to the end-user: this direct manipulation style mainly benefits novice IT users (Albinson and Zhai, 2003; Benko et al., 2006) thanks to a gentle learning curve. For its part, gestured-based interaction is an extremely intuitive interface—as it is based on inherent human capabilities—for handling applications that involve any artistic work. However, the mere incorporation of both interaction methods to human-machine communication process does not ensure end-user satisfaction. We must design a global interaction in which each element has a purpose and brings added value to user experience.

According to the established goal, we organize the rest of the paper as follows. The second section presents a brief summary of several supporting works and techniques. Then, we provide an overview

of *Sketch Arm* in order to put our work in context. The remaining two sections are focused on the user-system interaction: the fourth one provides a brief description of the different stages in the interactive closet design process, and the next one describes in more detail the various elements of the interaction system proposed to support design tasks. Finally, we present the most significant conclusions of our work and we identify future lines of action.

2 BACKGROUND

Multi-touch technology has been extensively studied in the past 20 years, in which many authors have focused their efforts, among other things, on (i) reducing the manufacturing cost of the supporting hardware (Han, 2005), (ii) enhancing its portability (Pinhanez et al., 2003) and sensitivity (Dietz and Leigh, 2001; Rekimoto, 2002), and (iii) developing software systems based on this new interface.

With regard to the last point, there are already several works in the literature that, instead of creating these systems as mere testbeds for the design of a new interaction proposal, seek to develop really useful tools. As an example, we can mention applications for purposes as diverse as medical imaging (Lundstrom et al., 2011), sketch design (Bae et al., 2008) and animation (Quevedo-Fernández and Martens, 2012), or information visualization in museums (Hornecker, 2008).

However, almost all of these applications are aimed to casual users—users with low IT skills—and its exploitation in professional contexts is usually neglected. In this sense, it would be interesting to examine to what extent this interaction may allow us to simplify the use of professional tools—eminently complex—, either to enable expert users to carry out their work expeditiously or to bring its use closer to novice users.

To that end, our paper presents a novel and attractive interaction proposal which minimizes the time and complexity normally associated with typical operations in CAD environments, within the professional context of furniture industry. While direct-touch interaction provides a greater interactive richness than traditional WIMP (Windows, Icons, Menus, Pointer) systems, the implementation of this touch-based interaction for common CAD tasks is not trivial. Among these tasks, the selection operation—highly performed in this kind of tools—is especially problematic. Specifically, the two main problems traditionally associated with using the finger as a pointing and selection tool are accuracy and occlusion.

Multiple authors have sought to determine the ideal size of GUI widgets in order to minimize the accuracy problem. Thus, Hall et al. point out in their 1988 study (Hall et al., 1988) that this accuracy can be 99.2% for targets with a size of 26 mm. Subsequently, however, A. Sears and B. Schneiderman note in his work (Sears and Schneiderman, 1991) that accuracy is maximized when the target has a size of 32 pixels—13.8 mm x 17.9 mm—. This study still holds true, being borne by different recent papers (Dandekar et al., 2003; Wang and Ren, 2009).

There are several additional approaches in the literature that have also attempted to solve the accuracy problem in traditional touch systems by (i) using a wider selection area or hot spot instead of the mouse cursor (Kabbash and Buxton, 1995), (ii) using both selection methods (Worden et al., 1997), or (iii) using resizable widgets (Bederson, 2000), that can dynamically change their size in order to provide a larger interaction area to users.

For their part, in relation to the occlusion problem, some authors have primarily focused their efforts on preventing the user from hiding the on-screen cursor with his fingers. The methods proposed to achieve this, range from applying a small offset above the user's fingertip—fixed in *Take Off*, a technique introduced by Potter *et al.* in (Potter et al., 1988), and dynamic in the case of the technique named *Dual Finger Offset*, introduced by Benko *et al.* in (Benko et al., 2006)—to the cursor, to the use of an on-screen call-out for displaying a copy of the occluded screen area (Vogel and Baudisch, 2007).

3 SKETCH ARM. SYSTEM OVERVIEW

Sketch Arm is organized into three distinct but closely related subsystems: (A) interactive sketching subsystem, (B) automatic design generation subsystem and (C) resulting model rendering subsystem. The first two subsystems are responsible for generating the 3D geometric information that represents the closet. The third one is responsible for providing a visual representation of the closet, created from that information, as the final output of the entire system. Figure 1 shows a diagram of the overall architecture of *Sketch Arm*.

As shown in Figure 1, subsystems A and B receive information from existing knowledge bases and data obtained from user interaction as input, and they both provide as output a geometric model that characterizes the closet structure. However, both subsystems deal with the creation of the model by significantly different strategies:

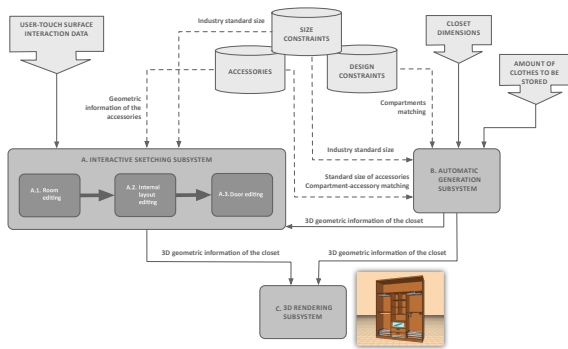


Figure 1: Overall architecture of *Sketch Arm*.

- The interactive editing subsystem takes as input data collected from the interaction between the user and the multi-touch surface of the supporting hardware device. This subsystem is intended to allow the end-user to emulate the creative process undertaken by professional designers and it provides him with the necessary tools to create and customize in real time the various constituent elements of the closet.
- The automatic generation subsystem demands almost no user intervention: the individual must provide only the dimensions of the closet and the amount of clothing he wants to store in percentage terms. This subsystem is able to generate autonomously different design proposals to meet both users' storage needs and, as far as possible, the design and dimensional constraints contained in the system. The paper (Rodríguez et al., 2013) provides a detailed description of this subsystem and the configuration of the proposed stochastic optimization algorithm for the automatic layout generation.

In the rest of the paper we will focus on the interactive editing subsystem. We will present the different tasks involved in the prototyping process and describe in more detail the interaction system we designed to support them.

4 DESIGN FLOW IN THE INTERACTIVE EDITING PROCESS

The design process consists of a set of operations for the three-dimensional parametric modeling of closets. This process is broken down into three sequential stages and each stage results in a functional module that gathers the relevant operations. Thus, we have a

room editing module, an internal layout editing module and a door editing module.

4.1 Room Editing Module

The primary aim of this module is to obtain a geometric model of the external structure of the closet from a basic outline of the room. The user defines this outline by creating the walls and pillars that make up the structural shape of the room. Then, the position, orientation and size of the closet are directly calculated, taking as a reference the geometry of the selected supporting wall. To do this:

- The origin of the closet is translated to the position of the origin point of the wall.
- The closet is rotated towards the direction of the normal vector of the wall.
- The width and height of the closet are determined by the corresponding dimensions of the wall. Depth, however, is constant and takes the standard value in closet manufacturing industry.

4.2 Internal Layout Editing Module

The design is completed by incorporating additional geometric elements to the basic model created in the previous stage. These representative elements of the internal structure of the closet include vertical and horizontal dividing elements, and instantiable elements or accessories —bars, drawers, etc.—.

While the addition of an instantiable element is just a simple assignment operation, introducing a dividing element is a complex process that causes the segmentation of a compartment into two new child compartments. This process involves the creation of new structural elements and also the computation of the transformation matrices needed to adjust each element to the local system defined by the interior of the parent compartment. Transformations are calculated, therefore, from the scale, position and orientation of this compartment.

4.3 Door Editing Module

Once the structure of the closet carcass has been detailed, all that remains is to create the front doors. This process involves three stages:

1. Constructing an initial basic geometric model for each door.
2. Dividing each door into panels.
3. Configuring the visual appearance of each panel.

The construction of the initial model of the door is automatic and completely transparent to the end-user: the system is responsible for defining the geometry of the model and computing the scale, translation and rotation matrices for proper rendering. However, the division stage demands user intervention like the edition of the internal layout of the closet, but it only allows horizontal dividers. Finally, in the visual appearance configuration stage the user can assign a material or color to each created panel as a texture of its front face.

5 INTERACTION SYSTEM

Sketch Arm interaction system rests on three major guidelines or design principles:

1. A simpler GUI
2. A touch-based interface for the direct manipulation of the elements in the design.
3. The minimization and simplification of mode switching.

Throughout this section we will present in greater detail the work we have carried out in relation to the outlined design principles and the solutions we propose to different problems associated with using the fingers for pointing and selecting.

5.1 Simplifying the GUI

The design of the graphical interface aims to give the user an access as immediate as possible to system functionality. We remove the superfluous elements of the application to get a clean, clear and minimalist interface that cedes part of its prominence to provide the end-user with a seamless and superior experience.

The tool is designed as a single landscape view that includes all the graphical elements of the user interface (Figure 2).



Figure 2: Layout of *Sketch Arm* GUI.

These elements are displayed on screen according to the usual layout of iOS Apps:

- The toolbar gives the user access to functionality for creating and modifying the different components of the closet.
- The drawing canvas is where the user performs the tasks involved in the design process. Through this central panel, the system gives constant feedback to the user, displaying in real time the design resulted from each operation.
- On the right of the drawing canvas we include a panel that provides direct access to both visual finishes for the different panels of the front doors and accessories that can be included inside the compartments of the carcass.
- The navigation bar allows the user to toggle between the different views associated with each functional module.

The design of the graphical elements must be aesthetically pleasing in order to create an engaging experience for the end-user. In touch systems it is also necessary to focus efforts on appropriately sizing these elements so as not to hinder the interaction. On the basis of the works (Dandekar et al., 2003; Sears and Shneiderman, 1991; Wang and Ren, 2009) referred in the state of the art, we adequate the GUI to fit the touch interaction style by following the seen dimensional guidelines. Thus, we set the toolbar buttons size to 40 pixels per side —14.1 x 14.1 mm—, the right panel buttons size to 54 pixels per side —19.1 x 19.1 mm—, and the width of the buttons on the navigation bar to 76 pixels and its height to 44 pixels —26.8 x 15.5 mm—.

5.2 Touch-based Interface for the Direct Manipulation of the Design Elements

The interaction between the user and the application is mainly channeled through the central drawing canvas. We assume that the first finger that touches the canvas, called primary finger, is the index finger of the dominant hand. Any additional touch is assigned to any other finger of either hand. We define four action templates to support the tasks involved in the design process: (i) single or multiple taps on any GUI control, (ii) single tap on any design element and then single tap on any GUI control, (iii) single tap on any GUI control and then single tap on any design element, and (iv) single tap on any design element and drag.

i. Single or multiple taps on any GUI control. The user taps with only one finger on a GUI control to

activate the corresponding tool and thus trigger the actions associated with it. This template is reserved for the use of certain functionalities —primarily to create new objects in the scene— that are implemented as automatism and require no additional user interaction to the simple activation of the tool. As seen in Figure 3, this action template is visible, for example, when the user adds a new door to the design: when the button is single tapped by a user, the system performs the construction of the geometric model of the new door autonomously.



Figure 3: Door creation process. Each single tap on the associated button triggers the calculations needed to parametrically define a new door and change the position and scale parameters of previously created doors.

ii. Single tap on any design element and then single tap on any GUI control. Firstly, the user single taps an object to select it. This way, the individual intentionally points to the object on which he wants to perform an operation. Then, the subject uses his finger again to tap the button associated with that operation to modify the selected object or as reference for adding a new element to the design. Thus, for example, to include a horizontal division inside the closet, the user has to first select a target compartment and then tap the shelves creation button. As shown in Figure 4, this interaction template is also evident in most of the editing operations, like the deletion of an element.



Figure 4: Deletion of an object from the design.

iii. Single tap on any GUI control and then single tap on any design element. There are some tools that, once selected, require an extra touch on the drawing canvas to create a new object at a specific location in the scene. The user explicitly provides the location by pointing his finger to a certain spot, which is an eminently natural gesture. The system translates the 2D coordinates of the touch event to the position coordinates of the target location in the 3D Cartesian space. This template is visible, among

other tasks, in wall creation: the user first selects the tool (Figure 5.1) and then creates the endpoints of the walls with successive single taps (Figure 5.2).

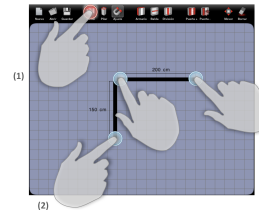


Figure 5: Creation of the walls that make up the shape of the room.

iv. Single tap on any design element and drag. Beyond specific object creation and deletion tools, there are some other ones that must be included in any CAD or rapid prototyping application. We are talking about translation and scaling tools. These operations, as we will see next, are closely related in our system.

To perform the translation of an object, the user must first tap the object to select it (Figure 6.1) and then, without lifting his finger from the touch surface, drag it across the screen to the target position (Figure 6.2). The translation ends when the user lifts the finger from the touchscreen (Figure 6.3).

As the user drags his finger across the drawing canvas, the object slides in such a way that it remains under the fingertip. This direct manipulation provides the user with an engaging experience, since the movement of the selected object thus conceived is predictable and transmits to the user the sensation of actually moving the object.

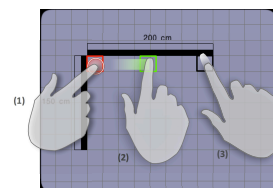


Figure 6: Translation of an object across the drawing canvas.

The translation of the object does not exclusively affect its position. We implemented an algorithm called *indirect scaling* that modifies the dimensions of the sketch elements that have some connection or relationship with the translated object. Thus, for example, when the user moves a divisor, the system automatically resizes both adjacent compartments and the accessories inside them.

Indirect scaling is significantly different from the approach commonly used in traditional CAD tools in which user must explicitly enter the dimensions for

each object by using a physical keyboard. The main alternative to physical keyboard in touch interfaces is the use of an on-screen keyboard, widely reviewed in the literature (Zhai et al., 2000) and extensively implemented in recent multi-touch mobile devices. Nevertheless, we reject the use of the touch keyboard due to its ergonomic and feedback problems (Lewis et al., 1997) that adversely affect the end-user's performance and comfort.

Our scaling mechanism enables an efficient object sizing in touch-based systems but it is inherently less accurate than directly typing the different values with a physical keyboard. To improve this, we implemented a non-intrusive accuracy mechanism. The user can naturally activate the accuracy mode while he is sliding an object across the drawing canvas. To do this, the user must keep the fingertip still on the object for 1000 ms. Thereafter, a smaller scale is applied to any object translation, thus increasing the movement accuracy. The user ends this mode by tapping anywhere in the canvas except on the object itself.

5.3 Scene Elements Selection Mechanism

The introduced action templates largely rely on first selecting an element of the sketch. This is common to many typical CAD tasks, which also require the selection of a specific object or entity to trigger a particular process.

While in desktop CAD tools the individual uses the mouse cursor, *Sketch Arm's* touch nature and the consequent absence of the on-screen pointer force the individual to use his finger as a pointing and selecting device, causing accuracy and occlusion problems. To solve both problems, we have implemented a number of specific mechanisms that seek to address them from different angles.

Additional viewport for displaying relevant information. Inspired by the *Shift* technique, introduced by Vogel and Baudisch (Vogel and Baudisch, 2007), our method also consists in including a small on-screen additional viewport when one finger taps the touch surface. This feature is only enabled for certain operations that demand high accuracy. However, unlike *Shift*, the viewport does not display a copy of the area occluded by the finger; it provides text information that is relevant in the operation context and fundamental for its successful completion. Figure 7 shows an example of the use of this technique to support the creation of walls.

After creating the first end of the wall, the system provides a real-time preview of it as the user drags his

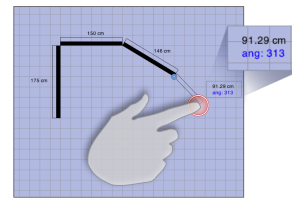


Figure 7: Using the additional viewport to enhance the wall creation process.

finger on the drawing canvas to set the other end. As shown in Figure 7, the finger itself prevents the individual from seeing the exact position of the second end, causing the loss of an essential reference for the successful creation of the wall. In order to prevent this, the additional viewport shows the exact length of the wall with an accuracy of two decimal places.

The auxiliary display area is shown when one finger taps anywhere in the drawing canvas and it is located in a position near the contact point. The magnitude of displacement between the finger and the viewport positions is constant. Thanks to this we avoid changing the user's visual attention during the object translation. For its part, the direction and orientation of the offset vary depending on the finger position in order to ensure that the viewport is always shown within the fixed limits of the canvas.

Non-visible expansion of the selectable area of an object. This mechanism seeks to solve the accuracy problem without visually change the size of the objects in the scene. A non-visible rectangular area is associated to each element of the sketch and acts as its selectable area: the graphical information of the area is not displayed on screen, but it is rendered to an off-screen buffer. Thus, we can increase the on-screen target size in order to facilitate the selection task while maintaining a realistic representation of the objects.

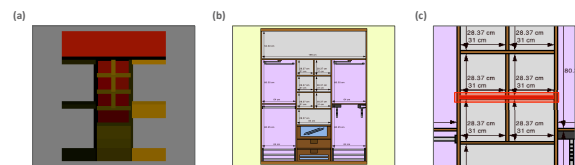


Figure 8: Expansion of the selectable area of the different elements of the closet carcass. (a) shows a representation of the color information for the corresponding selectable areas. (b) shows the on-screen displaying of the closet. In (c) we provide a graphic of how the selectable area expands the area of a closet shelf.

As shown in Figure 8, there is a clear center alignment between each element of the sketch and its corresponding selectable area. To expand the selectable area we assign to it dimensions that exceed the size of

the object itself.

Our selection algorithm is based on the color picking method, common in OpenGL or DirectX. To support this algorithm a unique color is assigned to each selectable area (Figure 8.a). A unique ID, consisting of the RGB color values of the area, is associated to the corresponding object. Having established this relationship, the algorithm is able to extract the color information of the exact pixel where the finger contacts with the selection area and then search the object whose ID matches the RGB data.

Increasing information space by using zoom. The zoom tool allows the user to adjust the information space to an appropriate size for selecting on-screen items comfortably. The implemented algorithm is based on the use of the standard pinch multi-touch gestures to make the zoom mode activation fully transparent to the user. This mode is automatically activated when the individual begins to drag two fingers describing a pinch-in or pinch-out gesture. The amount of zoom is calculated in real time from the distance between those two fingers.

5.4 Minimizing and Facilitating Mode Switching

Generally, mode switching means a change of context that usually involves interrupting the workflow. In this respect, it will be possible to streamline the user's tasks to the extent we are able to minimize the need to change between modes.

However, the wide range of features and functions that software design tools usually provide, significantly hinders this minimization: when the user interacts with this kind of tools, it is usual that he intentionally selects the corresponding dedicated control in order to activate the new mode.

Our approach is based on two strategies that seek to simplify the alternation between them. These strategies consist of (i) providing user transparent access to frequently used tools and (ii) using multi-touch gestures for switching between the different modes associated with these tools.

Sketch Arm provides fully transparent access to selection, translation and, as we have already seen, zoom tools:

- The selection mode is automatically enabled when the user ends any operation and disables its corresponding control.
- When the selection mode is enabled and an object is selected, a drag gesture with one finger enables the translation mode, as previously indicated. When the user lifts the finger from the

touchscreen, the translation mode ends and the selection mode is automatically enabled again.

- *Sketch Arm* allows switching to zoom mode at any moment, regardless of the current mode, when the user performs a pinch gesture. As soon as the user lifts one finger, the zoom mode ends and the existing context before its activation is recovered.

6 CONCLUSIONS AND FUTURE RESEARCH

As a result of the work we have done, *Sketch Arm* brings closet design to non-professional users by providing a touch-based experience and a virtually transparent interface that allows them to interact with the system in a natural manner. A user interface designed in this way, facilitates learning through the design process and generates on the individual the sensation of mastering the tools after little training. Below we summarize the main contributions of our work:

- Graphic user interface with an attractive and minimalist design.
- Design of control elements suitable for touch interaction.
- Touch-based action templates for a natural interaction in sketching tasks.
- A new approach to object scaling in touch-based systems called indirect scaling.
- The design and implementation of specific mechanisms to avoid occlusion and accuracy problems, caused by the use of a finger as a pointing device. Taking the Shift technique as a reference, we use an additional viewport for displaying relevant information in certain operations; we introduce an innovative technique that seeks to solve the accuracy problem by associating to each on-screen object a non-visible larger selectable area; and, finally, we simplify the switch between modes by using multi-touch gestures.

For further work, it will be necessary to conduct empirical studies in order to evaluate the goodness of the proposed interaction system in terms of the performance and error rate obtained by professional and novice users when performing certain tasks in the design process. It will also be desirable to make a comparative study to determine which kind of system, touch or desktop, is the most suitable for each considered user profile based on the individuals' performance and their subjective opinion.

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