

Pen-Based User Interfaces

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Pen-based user interfaces are emerging as an increasingly important aspect of computer and communications applications. This paper provides a brief summary of the major attributes of pen-based interfaces, including:

- The use of pen devices for pointing and selecting tasks,
- The use of pen-based gestures for command invocation,
- Issues and applications of electronic ink, which is used for various graphics and informal note-taking tasks, and
- A summary of current issues with pen-based handwriting recognition.

Introduction

Pen-based user interfaces are emerging as an increasingly important part of computer and communications applications. In the past, pen or stylus input was sometimes used instead of a mouse or trackball for basic navigation and selection tasks, and to provide graphics professionals with greater control and flexibility in using increasingly powerful graphics packages. However, because the computer feedback from the pen-and-tablet input appeared on a different screen than the pen input, these pen-assisted applications were visually disjointed to users.

Recent improvements in electronic digitizer and display technologies have led to an integrated tablet and display that enables direct targeting—pointing with a pen directly on the screen rather than using a mouse that is on another surface and plane. Other developments include more natural feedback for pen-based navigation and a renewed interest in electronic handwriting, called “electronic ink.” These new display technologies, in turn, have inspired renewed research interest in handwriting recognition for inputting text.

Pointing and Selecting With a Pen

Pen-based interfaces are characterized by a pen input device and a tablet display that offer the user:

- General selection and pointing input,
- Immediate command invocation through pen “gestures,” pen strokes a user draws

on a screen to initiate an action or series of actions,

- The ability to handwrite graphical data and informal text that can be stored as written, thus the term “electronic ink,” and
- The ability to enter alphanumeric data using handwriting recognition.

Many studies have been conducted in recent years to evaluate different pointing devices for tasks involving selecting and moving a cursor, and several of these studies have included pen input devices. These experiments show that users work about as effectively with a pen device as with a mouse, and work faster with either a pen or mouse than with a keyboard or a trackball. In an extensive review of various input devices,³ a pen device was favorably judged to make fewer mental and visual demands on the user, to be moderately easy to learn, and to reduce the chance of errors. More recent research has shown a marginal performance advantage using a mouse over either a pen (stylus) device or touch (finger) input for selecting tasks using current generic windows-based applications software. The difference, however, between mouse and stylus performance was considerably reduced when the input surface was adjusted to a more comfortable and natural writing position.⁴

A user’s acceptance of the input device is perhaps even more important than its performance. The pen often has been described as a natural pointing and selection

Acronyms and Terms Use in This Paper

Electronic ink — The ability of a computer system to accept handwritten graphical data and informal text, and store the data as written.

Gesture — Pen strokes a user draws on a screen to initiate an action or series of actions.

Objects — Graphic elements representing specific pieces of information.

Pen — Stylus-type device used to activate processes by pointing to icons or other graphic representations, or by writing.

tool. This is not surprising, given that users are familiar with traditional ink pens and their role in writing, highlighting, and marking up paper documents, and in pointing to specific items in a document during casual face-to-face meetings. Capturing the naturalness and flexibility of these and other typical uses of pen devices is a major challenge for designers of pen-based user interfaces.

Using a pen or stylus input device is similar to using touch or finger input. Indeed, both pen and touch input can access data faster than by using a mouse or keyboard to move a cursor, an advantage for inexperienced users. This direct access to screen objects—graphic elements representing specific pieces of information—also is more natural for button-oriented interfaces, such as cash machines, information kiosks, or computer-based telephones. The user need only push or tap a screen-generated button to invoke some action, rather than first positioning a cursor and then “clicking” on the soft button.

However, the benefit of direct selection with pen or touch interfaces comes at a price—obscuring some of the available choices. The pen’s advantage over touch systems is that it typically occupies less screen space, and the size of the target can be smaller. For a touch system to obtain a similar level of performance, the user interface would have to be rescaled to include significantly larger touch targets, as well as increased space between them. In short, a pen input device shares the direct selection characteristics of touch input while enjoying considerably more precise input targeting.

As a pointing and selection device, the pen presents several physical design challenges. Although it does not require a separate input area, such as a mouse

pad, a pen requires a tablet display surface that can be adjusted for different user needs. The tablet surface must be designed to lie easily on the surface of a typical office desk or table, be held casually in a user’s lap, or be cradled like a clipboard. The display surface and supporting enclosure need to present a smooth writing surface and a handrest. Finally, many users prefer an untethered pen that offers greater freedom of movement. Unfortunately, an untethered pen can be lost, so built-in pen “locators” or inexpensive and easily accessible pen replacements may be necessary.

Command Invocation Using Pen-Based Gestures

The second major characteristic of a pen-based user interface is that fewer pen strokes, or gestures, are needed to tell the system to take a specific action (see Figure 1). Several of the important benefits of gesture commands have been summarized by Wolf and Morrel-Samuels,⁵ and include:

- Greater efficiency by using a single gesture to replace the multiple steps of first selecting an object and then selecting the action to be performed on that object,
- Eliminating or reducing rigidly sequential commands, such as “click-hold-drag-unclick,” in favor what are called spatially-parsed commands, where a single stroke on a screen initiates the sequence,
- Greater feeling of control, as gestures are typically performed right on the object, and
- Being easier-to-learn, since electronic “paper” systems build on a user’s experience with paper-based gestures, such as proofreading commands.

In addition, gesture commands efficiently use display and input space, and may eliminate the need for keyboards and menus to enter commands.

Though the benefits of gesture commands are inviting, an important question remains about the degree of consistency in using gestures. Several studies have investigated this question. Wolf and Morrel-Samuels found generally high individual consistency in self-defined gestures (75 to 95 percent correct use of gestures). In addition, there were fewer gesture errors observed for tasks, such as phrase manipulation (i.e., position, delete, and move) and adding a space, but more mistakes were observed for insertion tasks (i.e., inserting a character, word, or phrase).

A more recent study proved that gesture consistency did not vary with either computer experience or

	Caret: opens a writing pad or creates a new document
	Check: displays options for whatever you draw it on
	Circle: opens an edit pad
	Insert space: adds a blank space in text or boxes pads
	Cross out: deletes whatever is beneath it
	Flick: (up, down, left, right) scrolls a page
	Pigtail: deletes a character in text or boxed fields
	Press: sets an insertion point. Press <i>and drag</i> moves the selection
	Tap: selects text or chooses menus and options
	Tap press and drag: copies a selection or object
	Undo: reverses the most recent action

Figure 1. Shown here are 11 core gestures that are defined in the GO Penpoint® Operating System. At least 40 additional command gestures have been defined for Penpoint, and new gestures can be added for individual software applications.

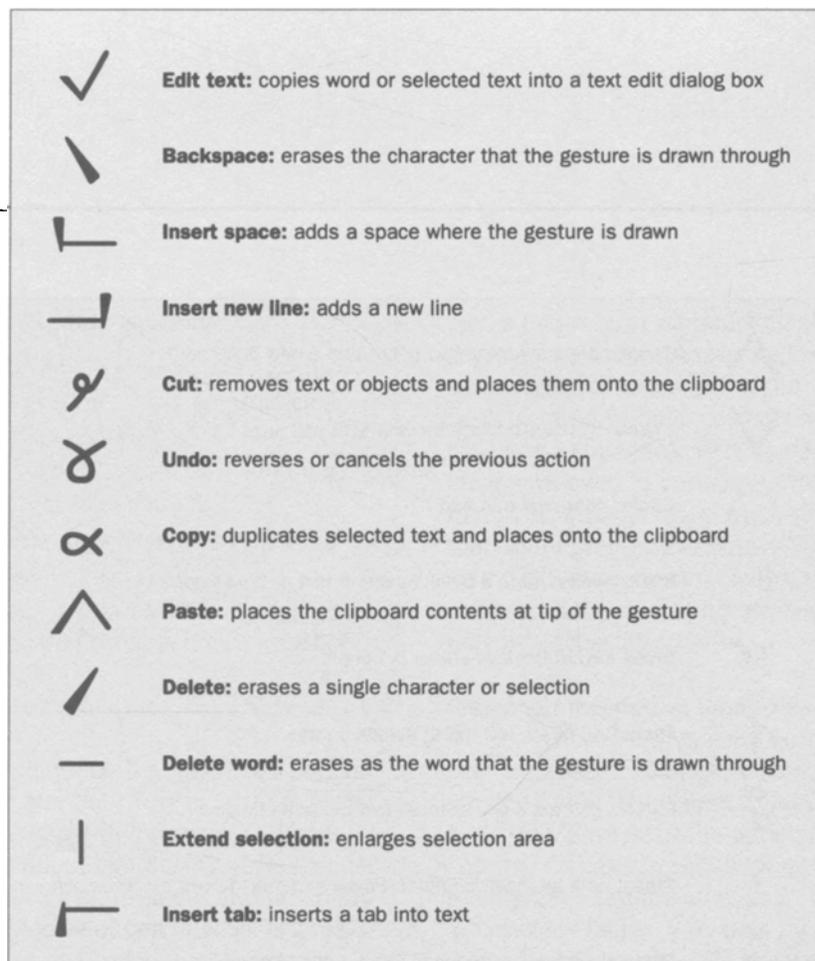
with the size and shape of the object target.⁶ Of considerable interest was the authors' observation that individuals used similar gestures to do similar tasks across several different application domains. For example, the circle gesture was used most often to select information for application domains that included text, spreadsheet, graphics, and forms entry. Both studies mentioned above concluded that defining intuitive and consistent gesture commands was feasible.

Recently, command gestures for common commands have been defined for two major computer operating systems. Figure 1 shows 11 core gestures defined in the GO Penpoint Operating System. (Penpoint is a registered trademark of the GO Corporation.) At least 40 additional command gestures have been defined for Penpoint, and new gestures can be added for individual software applications. As Figure 2 shows, a somewhat different set of six core and six additional gestures have been defined for the Microsoft® Windows™ for the

Penpoint operating systems. (Microsoft and Windows are registered trademarks of the Microsoft Corporation.) Here again, additional gestures may also be defined for new applications. As there are only a few pen-based applications that use command gestures, customers' use and acceptance of these gesture sets remain largely untested, as does the degree of customer demand for customizing individual gestures.

In a recent user interface concept study, gestures were explored for call-handling operations, such as a three-person conference call. Icons representing both the calling party and the called party appeared on the screen. The two icons were connected by a pen-drawn line to answer the call. To disconnect a call, a pen gesture that broke, or cut, the connection was used. For a three-way conference call, three icons were connected by a pen-drawn circle. While the circle gesture seems natural for conference call connections, it illustrates a potential problem with gesture commands. The circle

Figure 2. Shown here are the gesture set—six core, six additional—defined for the Microsoft® Windows™ for the Pen Computing Operating Systems.



gesture also is a core gesture that begins an editing task in the Penpoint environment, suggesting that core gestures across all applications may be problematical.

Electronic Ink

The third major characteristic of pen-based interfaces is the use of electronic ink as a new data type. Hand-drawn pen strokes are captured by the digitizing tablet, and an electronic representation can be stored, transmitted, retrieved, and altered as needed. If desired, electronic ink also can be passed to a handwriting or shape recognition application and be processed into text or graphics. Electronic ink's major uses are for recording informal or transient notes, and for developing and recording early draft sketches used in a graphical design process. There has been considerable research and application development for both individual, or "personal," ink applications, as well as group or collaborative work applications.

One use of electronic ink is for fast and natural recording of personal notes, "to-do" list items, and quick reminders. For example, the GO MiniNote® application allows entering and storing ink notes, followed by character recognition or embedding the note in other documents. (MiniNote is a registered trademark of the GO

Corporation.) Editing and manipulating electronic ink presents new user interface problems because it is often difficult to accurately parse, or recognize, one electronic ink object from another.

Several commercial products already have appeared that allow users with specially-equipped voice/ink terminals to have simultaneous voice and ink conversations over a standard telephone connection. These voice/ink terminals have been informally tested with small business customers and have yielded encouraging results. The concept of informal ink conversations is appealing to businesses, such as auto or appliance parts retailers, insurance claims adjusters, and graphic production companies that must communicate graphical information. Clarity of speech, speed of image creation and transmission, and prevalence of electronic ink-equipped telephones will be important factors in the success of this class of products.

Informal group notetaking also is a natural application of electronic ink. It is easy to envision electronically connected "blackboards" at different locations. These blackboards would be the electronic equivalent of large flip pads in note recording for various types of business meetings. Each blackboard would reflect whatever anyone wrote on any other blackboard during the

conference. In research on two collaborative drawing prototypes, Tang and Minneman^{7,8} identified several key requirements for such systems:

- There is a recurring need to be able to handle the negotiation between users at different locations for control of the "pen." The authors observed that collaborators often used non-pen communication techniques, such as hand gestures, pauses, and explicit verbal comments to help mediate the interaction.
- Because such collaborative work is interactive, users must be able to sketch in the same place at the same time.
- Though individual sketches can be shared with others, it may be necessary for the user to be able to alter another person's sketch.

These kinds of prototypes also highlight another key issue in pen-based collaborative systems—how to store the interaction in memory. For example, an associated search and playback facility can be used to record the electronic ink "conversation," or static "prints" of the conversation can be recorded at various times during the session. Other work on electronic sketching tools showed that essential characteristics of such systems must include rapid system execution and feedback, flexibility of pen input, and substantially complete session recording.⁹

Data Entry Using Handwriting Recognition

Handwriting recognition is one aspect of pen-based interfaces that has caught the interest of both the trade press and consumers. Several factors can account for this heightened interest. First, there is a growing demand for better ways to put text into small electronic devices. The ongoing trend to reduce the size of both computing and communicating devices (e.g., handheld computers, electronic personal organizers, and cellular telephones) is direct evidence that customers want smaller, more mobile products. Unfortunately, standard QWERTY keyboards become harder to use as button size and interbutton spacing are reduced, and handwriting recognition offers one solution to the space-constrained data entry problem.

Second, handwriting input remains a familiar and natural way to create and change alphanumeric information. Even those who are adverse to using keyboards can now enjoy the benefits of powerful computing devices.

Finally, the performance of handwriting recog-

ognition has improved considerably in recent years. This is due to direct user feedback on single-unit digitizer/tablets, improved resolution and processing capacity of the input tablets, and improved recognition algorithms.

While many variables affect a user's acceptance of a handwriting-recognition system, the most important is *recognition performance*. Unfortunately, there are no industry standards to test procedures or samples, and the specific testing conditions used for reported results are often unclear or unreported. Nonetheless, qualified comparative studies across handwriting recognizers have shown that character recognition rates for English text can be greater than 95 percent, with word level accuracy approaching 90 percent.^{10,11} Vallone¹⁰ and others have identified several important variables that influence recognition performance and user acceptance of handwriting recognition systems. These variables include:

- The range of symbols recognized (uppercase, lowercase, punctuation),
- Character separation (discrete, versus overlapping, versus connected),
- Error correction facilities (providing best match and next best choices),
- Speed of recognition (the time from input completion to recognition),
- Stroke-order independence (the ability to allow temporally disconnected character input, such as crossing a "t" or dotting an "i" at the end of the word), and
- Adaptation (the system's ability to "learn," or improve performance passively, as additional user samples are collected over time).

Unfortunately, handwriting recognition systems still need to be significantly improved. Recent studies comparing data entry with a keyboard, versus a handwriting-recognition system, showed that input time was considerably slower for handwriting.¹² Industry trade articles also have reported that some pen system users find the performance of commercially available systems unacceptable for some tasks, especially those involving large text input. As improvements in recognition technology continue over the next few years, customer acceptance will improve.

While handwriting recognition currently may be the most typical and exciting method of pen alphanumeric entry, it should be remembered that pen-based interfaces can support alphanumeric data entry without using handwriting recognition. A display-generated, "soft" keyboard can be combined with a pen to select specific

Figure 3. An A&T prototype of a pen-based user interface designed for communications applications: (3a) The pen is used as a pointing device to select an application from a menu of choices. (3b) The pen is used to enter informal notes for storage and retrieval. (3c) The pen is used to enter alpha information into data fields using handwriting recognition.

characters. While this may be an acceptable—even preferable—alternative to handwriting input for some users, it is unlikely that this input method would result in faster, more accurate data entry performance.

Summary of Pen-Based User Interface Attributes

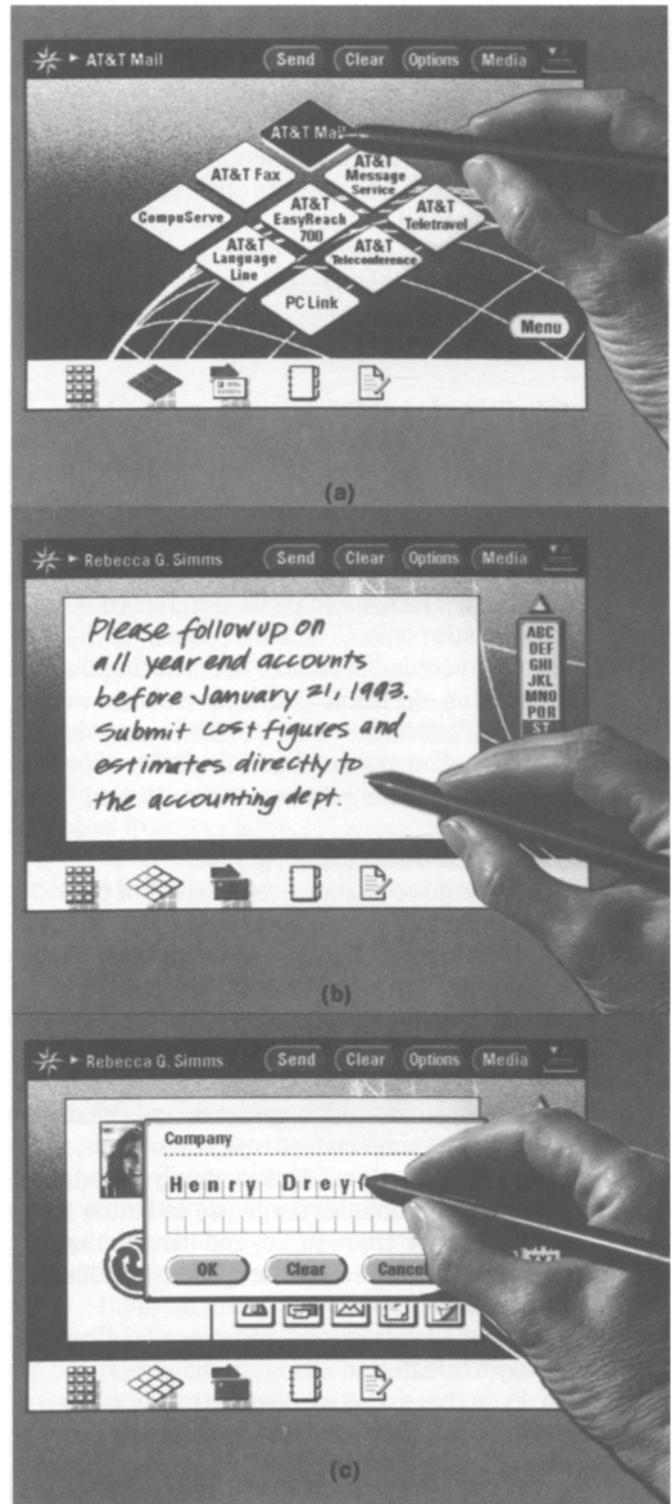
The key characteristics of pen-based user interfaces suggest many important user benefits. For selecting and pointing, pen devices offer natural and direct positioning, with performance at least as good as existing alternatives. Research has shown the overwhelming advantage of a pen device over keyboard alternatives for pointing tasks. Pen interfaces also are enabling innovation in using gesture commands to more efficiently combine object selection and action tasks. It also appears that there may be natural gestures that can be defined for many common tasks.

Pen interfaces allow electronic ink to be used for informal data entry and drawing. There is no doubt these interfaces will be an important part of visually enhanced communication as both local and geographically dispersed work teams use ink to record meeting notes and exchange graphical information.

Finally, by using handwriting recognition, pen interfaces can provide alphanumeric input that may someday approach the naturalness and efficiency of paper and pen. While handwriting recognition is robust enough for many small or constrained input tasks today, it will be used in more tasks as the technology matures.

The promise of pen interfaces also includes being able to span a complete range of user tasks. The current combination of a keyboard and a pointing device, such as a mouse, requires users to frequently change their focus and hand placement from one input device to another. Pen interfaces, however, let the user select and position, draw, and enter data using only a pen.

Besides allowing single input, pen interfaces also make efficient use of space. By combining the input area, or digitizing surface, with the output area, or display,



pen interfaces require considerably less space than a display using a keyboard and pointing device. This makes pen interfaces particularly attractive for small, handheld products.

Emerging Products and Applications

In the past two years there has been a sharp increase in commercially available pen-based products and applications. Several vendors have introduced pen computers that run industry- or company-specific software, such as forms data entry or inventory tasks. AT&T has become a significant entrant in the pen-based product arena, leading other manufacturers with its NCR 3125[®] pen computer.

The company also has developed a prototype of a pen-based user interface specifically designed for communications applications. It was designed and developed to explore how a pen user interface can accomplish several communications tasks. In Figure 3a, the pen is being used as a pointing device to select an application from a menu of choices. In Figure 3b, the pen is used to enter informal notes for storage and retrieval. A similar interface was designed to provide an interactive ink conversation with someone with a similarly equipped pen communications device. And finally, in Figure 3c, a pen device is used to enter alpha information into data fields using handwriting recognition.

User testing of this pen interface is still under way, but early results have been encouraging. User feedback confirms the benefits of the pen as a precise, direct access pointing device. There also have been positive comments that support the naturalness of a pen interface.

No doubt, pen-based user interfaces will continue to evolve and appear with new products. They already have proved useful for basic selection and navigation tasks, as well as for informal writing and drawing tasks. The widespread adoption of pen-based gesture commands will require both a good standard set of gestures and demonstrable performance advantages over other command access alternatives. And as handwriting recognition performance improves, the use and success of pen-based text input will increase.

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