(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 August 2006 (03.08.2006)

PCT

(10) International Publication Number
WO 2006/080927 A1

(51) International Patent Classification:
H03M 11/00 (2006.01) *H03M 13/00* (2006.01)

(21) International Application Number:
PCT/US2005/003093

(22) International Filing Date: 27 January 2005 (27.01.2005)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **EATONI ERGONOMICS, INC.** [US/US]; 42 West 24th Street, New York, NY 10010 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **GUTOWITZ, Howard, Andrew** [US/US]; 50 Park Terrace East, Apt. 2F, New York, NY 10010 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

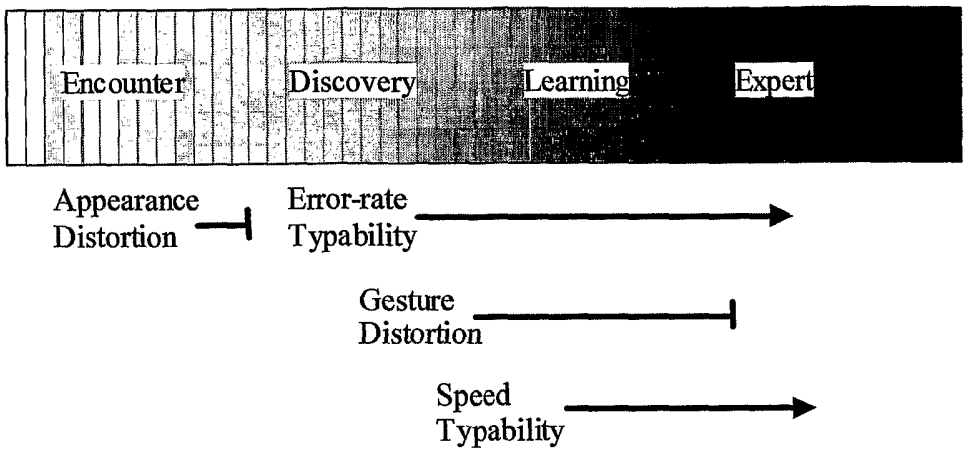
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** TYPABILITY OPTIMIZED AMBIGUOUS KEYBOARDS WITH REDUCED DISTORTION



(57) **Abstract:** It has been discovered how to make novel ambiguous keyboards which are both a) sufficiently typable to be attractive to expert users, and b) sufficiently similar to conventional keyboards [330] to be attractive to novice users. In general, unambiguous conventional keyboard [330] layouts make poor text-entry devices when straight-forwardly reduced in size. The straight-forward reduction involves reducing the number of keys and placing several letters on each of the keys whereby the keyboard [330] becomes ambiguous. The highly non-obvious engineering feat is to perform the reduction while maintaining a familiar look and feel, and without overly compromising text-entry capacity. The secret is to conceive of keyboards [330] which are a small perturbation of a conventional keyboard [330], choosing the perturbation adroitly so that typability is maximized.

WO 2006/080927 A1

Typability optimized ambiguous keyboards with reduced distortion

Inventor

HOWARD ANDREW GUTOWITZ

50 Park Terrace East, 2F

New York, NY 10034

Assignee

EATONI ERGONOMICS, INC.

42 West 24th Street

New York, NY 10010

1 Field of Invention

This invention relates generally to computerized text-entry systems based on ambiguous keyboards, more specifically to typability optimized ambigous keyboards with reduced distortion.

Patent Documents Cited

US patent 6219731, US patent applications 09/856,863, 10/415,031, and 10/605,157 and all others sharing their priority dates, all incorporated by reference.

Introduction

The first response to change is rejection. In order to improve the usability of a keyboard, its appearance may need to be changed. Yet changing a keyboard from a familiar design makes the keyboard appear at first sight to be less usable. Perception of usability and real usability are at odds. Thus, there is a long-felt but unexpressed need to design keyboards which, despite being novel, are perceived to be usable, thanks to their similarity to products known to be usable. While similar tensions arises in the introduction of many new technologies, this invention teaches solutions to the problem in the particular domain of ambiguous keyboards. Herein disclosed are ambiguous keyboard designs which are novel in that they are of improved typability with respect to a conventional design, yet are of sufficiently minimized distortion with respect to the conventional design that they invite approach and experimentation on the part of naive users.

To minimize distortion, distortion must be appropriately defined, measured and controlled. In the same way, to maximize typability, typability must be appropriate defined, measured, and controlled. To achieve the goals of this invention, new measures of both distortion and typability are introduced. It is shown how to use both these new measures and prior-art measures to synergistically combine distortion minimization with typability maximization. This gives the unexpected result of making devices which appeal to both novice and advanced users.

This invention introduces a novel class of devices which are both of acceptable layout distortion and acceptable typability, where both aspects are important enough to require compromise between the two. Prior-art methods sought to optimize with respect to only one or the other set of constraints, and then, only certain aspects of either layout distortion or typability were considered. Until US patent application by Gutowitz 09/856,863 hereby incorporated by reference, there was no suggestion in the literature that layout distortion and typability

were related, much less could be simulaneously optimized, as is taught by the present invention.

This invention teaches how to construct devices which synergize the teachings of maximizing typability and mimizing distortion. It is in particular highly non-obvious to measure or minimize distortion, as distortion is a psychological, not physical, property. The initial impression of the device, the promise of usability that the design conveys by its appearance, is at least as important to the commercial success of a device as the actual usability of device when used. Designs which seek to increase typability without limiting distortion do not usually succeed. For example, the Dvorak keyboard (Fig. 3C), did not succeed, despite great fanfare and a claim to improved typability over the dominant qwerty keyboard. This failure may be traced to the fact that Dvorak made no attempt to smooth the rupture between his keyboard and convention.

Since prior art keyboard designers either stick slavishly to convention, or radically alter it, nothing heretofore teaches us to combine typability optimization with distortion limitation, or how to perform this combination. While prior-art designers are focussed *either* on initial product adoption, *or* on performance for expert users, for a product to be a real success it has to do both. This invention teaches how to seek commercial success for improved keyboards in a systematic fashion.

Though we are concerned with the *appearance* of devices, our discoveries are in the realm of engineering, not aesthetics. We seek to engineer perceived comfort and familiarity, not perceived beauty. To achieve these engineering goals, several novel measures introduced which capture the intuitive meaning of "distortion" in the calculation of physical properties of layouts. By means of these measures, a search through the space of alternate layouts can be conducted to find layouts which meet the design constraints.

Up to now, the earliest period to be considered in ambiguous keyboard design is the discovery period (US Patent Application 10/415,031 by Gutowitz and

Jones). During the discovery period, the user does actual manipulation of the device. In the pre-discovery period, the appearance of the device, the period of *imagining* what it would be like to use the device is essential. The pre-discovery period is a main focus of the present invention.

Definitions and Basic Notions

This section collects definitions of words and concepts which will be used in the following detailed specification.

Language. Given a set of symbols, one can construct sequences of symbols, and assign probabilities to the sequences. The set of symbols, sequences of symbols, and the probabilities assigned to the sequences will be referred to here as a language. For clarity of discussion, and without limiting the scope of this invention, the languages we will refer to are written natural languages, such as English, and though for concreteness we may refer to symbols as "letters" or "punctuation", it will be understood by those of ordinary skill in the art that symbols in this discussion may be any discrete unit of writing, including standard symbols such as Chinese ideograms or invented symbols such as the name of the artist formerly known as Prince.

Ambiguous codes. Ambiguous codes are well known in the art. On the standard telephone keypad used in the United States, there are 12 keys, 10 of which encode a digit, and several of these, typically 8, encode in addition 3 or 4 letters of the alphabet, arranged in alphabetic order. These assignments produce an ambiguous code which we will call the standard ambiguous code (SAC). This code is abc def ghi jkl mno pqrs tuv wxyz.

Disambiguation Method. Since several letters are encoded on each key in an ambiguous code, some method of disambiguation must be used to decide which of the several letters is intended by the user. The disambiguation method is typically software which predicts which sequence of letters is intended by the

user, based on the user's previous input and a database of linguistic information.

Conventional keyboards. There are essentially three standard keyboards in wide use for Latin alphabets: the qwerty keyboard and its close variants and the 12-key telephone keypad with the standard ambiguous code described above. Other scripts have other keyboards, and it will be appreciated that any device or method described here applies as well to those keyboards for other scripts.

Layouts. A layout is an assignment of letters to keys where the keys are in some spatial arrangement. When no confusion will arise, the words keyboard and layout may be used interchangeably.

Layout distortion. In this disclosure we are concerned with pairs of keyboards: a convention keyboard, and a distorted keyboard which is derived from the convention keyboard by moving some letters from their position in the conventional keyboard. The layout distortion is the difference between the conventional keyboard and the derived keyboard. There are two main classes of layout distortion: order distortion and partition distortion.

Order distortion. The order of a layout is the order in which the labels of keys would be read by a reader of the language whose script is typed by the keyboard, e.g. English is typed with Latin script by the qwerty keyboard, and the keyboard is read left to right, top to bottom, qwertyuiopasdfgh.... A order distortion is a displacement of a letter from its conventional position in the order.

Partitions. A partition of an integer n is a set of integers such that the sum of the elements of the set is equal to n. Typically, a given integer admits many partitions, e.g. the integer 5 has the partition 3:2, but also the partition 2:2:1. Algorithms for generating all the partitions of an integer are well known to those skilled in the art. There are various characteristics of partitions which are relevant to this disclosure, some of which are defined immediately below.

Even-as-possible. Most prior art codes use an even-as-possible partition. That is, a partition in which, to the extent possible given the number of keys in relation to the number of letters to be encoded, the number of letters per key is

the same. Even-as-possible may be abbreviated as EAP.

Row distortion. Most conventional keyboards comprise keys organized in a regular, typically honeycomb, array with identifiable rows and columns. If a letter is displaced from its conventional row in a new layout, then the new layout has a row distortion. Column distortion is defined in the same way.

Range. The range of a partition is a generalization of even-as-possible property. The irregularity of a partition is defined as the difference between the minimum and maximum number of letters assigned to any key. If the conventional keyboard is an unambiguous keyboard with one letter per key, then, intuitively, the lower the irregularity of the distorted keyboard, the less the keyboard is perceived as distorted.

Dominant class. The dominant class of a partition of letters onto keys is the largest number of keys which the same number of letters. Thus the dominant class of the partition of letters onto keys (4,3,3,1) is the two keys with 3 letters each. Intuitively, the bigger the dominant class in relationship to the total number of keys in the partition, the more the keyboard is regular. Two partitions may have the same range, but have a different number of keys in the dominant class.

Gesture distortion. Layout distortions may be classified as to whether and to what degree the movement of letters from their positions in the conventional keyboard to the distorted keyboard changes the gestures which are used to type the letters. For instance, exchanging the letters q and a on the qwerty keyboard would not affect which finger is used to type either q or a, so the exchange is equi-finger, though it does change the distance the finger must move to type the letter. In both the qwerty keyboard and the distorted keyboard, both q and a are typed with the left little finger by a touch typist.

Typability. Typability refers to the work or time required to enter text. A commonly used measure of work for an ambiguous keyboard is kspc (average keystrokes per character). The amount of time needed to enter text may not be simply related to the kspc. Various processes may have to occur in addition to

pressing keys in order to enter text, and these processes take time. For instance, if a word-based disambiguation method is used, and more than one word corresponds to the keystroke sequence used to enter the intended word, then time will be required to examine and select from the possible candidates the intended word.

Drumroll effect. The drumroll effect is a typability constraint relating to the time required to enter text. In general, not all keystrokes take the same amount of time. For instance, if each of a pair of letters in a sequence are typed with different fingers, the sequence may be entered more quickly than if they are typed with the same finger. While a first finger is entering the first letter, the second finger can moved into position to enter the second letter. The first and second keystrokes are thus overlapped in time. This overlapping is called the drumroll effect.

Fitts' Law. Fitts' law is a mathematical model used in typing studies to estimate the time needed to make a keystroke depending on the size of the keys and the distance between keys. The longer the distance, the larger the time, and the larger the keys, the shorter the time.

Steric Hindrance. A term of art borrowed from chemistry. It refers to hindrance between otherwise freely moving objects whose motion becomes hindered when the objects are close to each each other, due to the fact that the objects occupy space. Steric hindrance must be taken into account when the size of the keys is small compared to the size of the finger or thumb used to type the key. The steric hindrance effect can modify the results of both drumroll and Fitts' law analyses.

Interaction Mechanism. The interaction mechanism is physical means the user uses to interact with the keyboard. For instance, the telephone keypad is often typed with one finger, or one thumb, or two thumbs. Which interaction mechanism is used may be depend on many factors, depending on the experience of the user and/or other activities the user is engaged in at the time of text entry,

e.g. holding a cup of coffee in one hand may prevent a user from using a two-thumb interaction mechanism which she would otherwise prefer. Some typability measures depend on the interaction mechanism, while others do not.

Disambiguation software. When there is more than one letter on a key, some means is needed to select which one is intended by the user at any given time. The selection could be mechanical (e.g. hit the key once for the first letter, twice for the second letter, ...) or it could be determined by an algorithm which guesses what is intended depending on context and the statistics of language. Such software is called disambiguation software.

Next function/key. Word-based disambiguation systems use a Next function to allow the user to change the word displayed if the currently displayed word is incorrect, character-based systems use a Next function to allow the user to change the letter displayed if the currently displayed letter is incorrect. These functions will be referred to generically as the Next function, and a key executing the function will be referred to as the Next key.

Typability optimized keyboards with minimized distortion. A keyboard with a given value of distortion is said to be optimized with respect to a typability constraint if it is among the best keyboards with respect to the typability constraint, and has substantially the given value of distortion. For example, take the typability constraint to be lookup error rate, and the distortion measure to be the number of pairwise interchanges to map the distorted keyboard to the qwerty keyboard. If the limit in distortion is 5 pairwise interchanges, then an optimized keyboard with distortion limit 5 is a keyboard with among the best lookup error rates for all keyboards with distortion 5 or less.

Brief Description of the Drawings

Fig. 1) The stages of product adoption.

Fig. 2) Summary of some relevant prior art.

Fig. 3) Presentation of Dhiatensor and Dvorak keyboards.

Fig. 4) Presentation of qwerty, azerty, 5-column qwerty, and Cyrillic conventional keyboards.

Fig. 5) Layouts with order-persevering and non-order preserving distortions of Gutowitz '863.

Fig. 6) The half-qwerty keyboard of Matias US Pat. No. 5,288,158.

Fig. 7) Block diagram of a typable device based on an ambiguous keyboard.

Fig. 8) Chart of illustrative typability constraints.

Fig. 9) Touch typability regions and effective key number as defined by Gutowitz '863.

Fig. 10) Illustrative keystroke per character results of the character-based disambiguation of Gutowitz US Pat. No. 6,219,731.

Fig. 11) Chart of illustrative appearance distortion constraints related to partitions.

Fig. 12) Chart of illustrative appearance distortion constraints related to order.

Fig. 13) Illustration of the design of a quantitative distortion measure related to partitions.

Fig. 14) Even-as-possible qwerty-like layouts on various number of columns, following Gutowitz '863.

Fig. 15) Chart of illustrative gesture distortion constraints.

Fig. 16) Flow chart of a method for making a typability optimized keyboard with reduced distortion.

Fig. 17) Summary chart of embodiments illustrating typability and distortion tradeoffs.

Fig. 18) Flowchart of illustrative method of making a practical typability optimized keyboard with reduced distortion for a telephone keypad.

Fig. 19) Effective key number of the best layout found with a given value of layout range and no order distortion.

Fig. 20) The layouts corresponding to the points of Fig. 19.

Fig. 21) Distributions of effective key number as a function of the number of order distortions.

Fig. 22) Summary of results of applying the method of Fig. 18.

Fig. 23) A illustrative best result from applying the method of Fig. 18.

Fig. 24) The results of applying the method of Fig. 18 to a 5-column qwerty-like keyboard.

Fig. 25) 5-column qwerty-like keyboards with a range of order distortion.

Fig. 26) Diagram of an illustrative navigation keypad.

Fig. 27) An alphabetic-order preserving layout for a navigation keypad.

Fig. 28) A qwerty-order and two-thumb gesture preserving layout for a navigation keypad.

Fig. 29) A conceptual distinction layout for a navigation keypad.

Fig. 30) A telephone-keypad-row-preserving layout for a navigation keypad.

Fig. 31) An illustration of steric hindrance due to a large thumb size/key size ratio.

Fig. 32) Application of the drumroll constraint to evaluate two-key layouts.

Fig. 33) An example of drumroll optimization in view of steric hindrance, by means of symbol multiplication.

Fig. 34) A gesture-preserving qwerty-like layout for a steering wheel.

Fig. 35) Typability distribution for keyboards typability optimized simultaneously for two distinct interaction mechanisms.

Fig. 36) Example layouts simultaneously optimized for two interaction mechanisms.

Fig. 37) Flow chart for predictive compensation for distortion.

Summary of the disclosure

The disclosure begins by establishing a framework in terms of the stages of product adoption. It then explains, by means of numerous examples, the meaning of distortion and typability, and shows how to measure these.

A number of non-limiting embodiments are shown as examples to illustrate the scope of the invention. This scope is not limited by the kinds of typability or distortion discussed, and the particular constellation of typability constraints and distortion constraints used in each embodiment are for the sake of illustrating how these heretofore disjoint concepts can be synergistically combined. More than one kind of typability and more than one type of distortion can be combined, and combined as well with other types of distortion and typability not discussed here. The principles revealed operate in a quite general setting, allowing many variations which will be appreciated by one skilled in the art. The non-limited examples discussed here are merely for the sake of illustration, and the true scope of the invention is to be appreciated from the appended claims.

Objects of the invention

It is an object to create ambiguous keyboards optimized for more than one stage of the product adoption process.

It is an object to optimize keyboards relative to typability constraints including but not limited to: lookup error, qwerty error, effective key number, keystrokes per character, drumroll probability, effective drumroll probability, Fitts' law, throughput, robustness, and language generality.

It is an object to optimize keyboards relative to partition-related appearance distortion constraints including but not limited to: even-as-possible, maximum or minimum number of letters per key, range, dominant class, left-right symmetry, up-down symmetry, and monotonicity.

It is an object to optimize keyboards relative to order-related appearance distortion constraints including but limited to: reading order, row-limited reading order, column-limited reading order, exterior-weighting, row-limited letter movement, column-limited letter movement, distance-limited letter movement, number of letter displacements, and number of letter exchanges.

It is an object to relate appearance distortion to quantifiable mathematical models, suitable for use in an optimization method.

It is an object to optimize keyboards relative to gesture distortion constraints including but limited to: same digit, symmetric digit, same hand, nearby digit, and same gesture class.

In is an object to show how to make and use typability optimized ambiguous keyboards with reduced distortion.

It is a further object to present appearance distortion optimized ambiguous keyboards optimized for typability.

It is a further object to present gesture distortion optimized ambiguous keyboards optimized for typability.

It is a further object to present distortion optimized ambiguous keyboards optimized for drumroll effect typability.

It is a further object to present layouts based on a conceptual distinction.

It is an object to present keyboards optimized respecting digit hindrance.

It is a further object to present ambiguous keyboards optimized with respect to more than one typability measure.

It is a further object to present practical solutions to mapping conventional keyboards to the telephone keypad, while optimizing typability and reducing distortion.

It is a further object to present ambiguous keyboards optimized with respect to more than one distortion measure.

It is an object to present ambiguous keyboards with optimized gesture distortion suitable for a gripped object such as a steering wheel or handle bars.

It is a further object to present ambiguous keyboards with optimized gesture distortion suitable for a navigation keypad.

It is a further object to present ambiguous keyboards for a navigation keypad based on alphabetic ordering.

It is a further object to present ambiguous keyboards for a navigation keypad based on alphabetic ordering and row-compatible with a telephone keypad.

It is a further object to present appearance distortion optimized ambiguous keyboards optimized for typability compatible with a keypad which comprises three rows and 1-9 columns.

It is an object to present appearance distortion optimized ambiguous keyboards optimized for typability and compatible with a telephone keypad.

It is an object to present distortion-optimized keyboards with two letter keys.

It is an object to present layout distorted keyboards which are easy to explain and remember.

It is an object to present keyboards which are optimized with respect to more than one interaction mechanism.

Further objects will become apparent through the detailed description of the invention to follow.

Detailed Description of the Invention

Introduction

Fig. 1 gives an overview of the invention, showing how the various aspects of the invention relate to the stages of maturity of the product adoption process of the user.

Encounter. In the encounter stage, the user has not yet used the device, but has only seen it, perhaps in a photograph. The only experience the user can have of using the device is his or her mental projection as to what it would be

like to use the device. We will call this mental projection the initially perceived usability. The initially perceived usability will be based on actual experiences the user has had with similar devices. One of the discoveries on which this invention is based is that the initially perceived usability can be maximized as the layout distortion from a conventional layout is minimized.

Discovery. In the discovery stage, the user begins to handle the device, and tries to use it to enter text. Research shows that users will typically only make a few initial experiments in entering text before abandoning the device, if these first experiments are not promising, that is, if the device seems hard to use, does not give expected results or otherwise does not "feel right". It is thus essential that the disambiguation software does not make too many mistakes and otherwise confuse the user in this stage. The number of mistakes the disambiguation software makes is related, in part, to the layout. Given a particular disambiguation method, the layout can be modified to reduce the number of mistakes. One aspect of this invention is to solve the design problem which arises: modifications to the layout to reduce disambiguation mistakes typical reduce initially perceived usability, as they distort the keyboard layout from its conventional form. Thus optimizing for success in the discovery phase may conflict with optimizing for success in the encounter stage.

Learning. In the learning stage, the user who has decided to adopt the device begins to gain mastery, seeking speed and accuracy of text entry though continued practice. Good disambiguation, which first gains importance in the discovery phase, continues to be important. By contrast, initial perceived usability has faded in relevance, as the user now is basing perceptions on actual use of the device. Still, the influence of the conventional design remains, as motor gestures which have been ingrained in the user by long use of the conventional design continue to be active. In the same way that learning to pedal a bicycle leverages already learned motor patterns of walking, any conservation of gesture from the conventional keyboard to the novel keyboard on which it is based will

accelerate learning of the novel keyboard. Thus a further aspect of this invention is to provide keyboards which minimally distort gestures used to operate the conventional keyboard, and yet are optimized with respect to the disambiguation mechanism.

Expert. In the expert stage, not only has the initially perceived usability been replaced by actual experience in using the device, conventional gestures have been modified or replaced by gestures adopted to the new keyboard. Users of the new keyboard may develop an interaction mechanism with the device which has little relationship with the conventional interaction mechanism on which it is based. A further aspect of this invention is to perform expert interaction mechanism optimization in a way which is minimally disruptive to optimizations designed to improve user experience at earlier stages of development.

The stages of encounter, discovery, learning, and expert are similar to the stages of romantic involvement, roughly, first sight, flirting, courtship, marriage. The analogy is appropriate in that users may develop very deeply ingrained patterns of interaction with their keyboards, and yet choose which keyboards to become involved with based on criteria which are rather different from those which are critical to success in advanced stages of the relationship.

What will be taught by means of illustrative examples, and claimed in the appended claims, are a set of devices which synergistically combine optimizations directed at more than one level of keyboard adoption. The disclosure seeks to inform the person of average skill in the art to appreciate how to balance optimizations directed at one stage against optimizations directed at another stage, arriving at a keyboard which is both likely to be adopted, and once adopted, will perform effectively.

It should be appreciated that it would be easier to perform such optimizations directed at one stage only. A keyboard could be chosen which is best for each stage. However, learning a keyboard means learning motor reflexes which rapidly input symbols, if the keyboard were to change en route, then these gestures

would have to be relearned. Further, typical hardware keyboards do not allow the assignment of letters to keys to be easily rearranged. This invention thus solves a problem which is both difficult and heretofore unfelt.

Prior Art

Turning to Fig. 2, we find a chart of selected relevant prior-art keyboards.

The qwerty keyboard (Fig. 4A) is the archetype of a conventional keyboard layout. It is well-established as a convention in the English-speaking world, and other Latin-script languages typically use a conventional keyboard which is a close variant of qwerty. An example, the azerty keyboard used in France, is shown in Fig. 4B. Though these other keyboards can be considered to be distortions of the qwerty keyboard, they are not ambiguous keyboards and they are not optimized for typability. Other conventional keyboards exist for other scripts, such as the keyboard of Fig. 4D, for the Cyrillic script.

The Dhiatensor keyboard (Fig. 3A and Fig. 3B) is relevant as it is an early example of a keyboard optimized for a two-finger interaction mechanism. The letters are placed in order of probability, from the center outward and from bottom to top row. It is not an ambiguous keyboard, and it not a distortion of a conventional keyboard. Indeed, this keyboard was designed before there were well established conventions for typewriter keyboard layouts.

The Dvorak keyboard (Fig. 3C)), is optimized for an 8-finger interaction mechanism. It seeks to minimize the distance fingers must travel to type the most common letters. It is not an ambiguous keyboard, and it is not distortion minimized. Though qwerty was well-established as a convention at the time of invention of the Dvorak keyboard, Dvorak did not attempt to conserve any part of that convention in his design.

The half-qwerty keyboard of Matias (US Pat. No. 5,288,158) of Fig. 6 is a gesture distortion limited keyboard. It attempts to conserve typing gestures

from the qwerty keyboard by "folding" the qwerty keyboard in half, such that letters typed with a given finger on the qwerty keyboard are typed with the same finger (though perhaps of a different hand) on the half-qwerty keyboard. The half-qwerty keyboard is not an ambiguous keyboard, and it is not optimized for typability.

US patent application Gutowitz 09/856,863 herein incorporated by reference and allowed as of the date of this present application will hereinafter be referred to as Gutowitz '863. Gutowitz '863 provides a background for a number of the new inventive concepts presented here. That disclosure introduced qwerty-like partition- and order-distorted keyboards, explored the advantages of even-as-possible and non-even-as-possible layouts, and provided a focus on two-letters-per-key layouts. Some example embodiments from Gutowitz '863 are shown in Fig.5. Fig. 5A shows a partition-distorted version of a conventional alphabetic layout for a telephone keypad. Fig. 5B shows a qwerty-like layout on 7 columns, with a monotonically decreasing number of letter-assigned keys per row, with partition distortion to optimize typability. Fig. 5C shows a qwerty-like layout on 7 columns with partition and order distortions. The number of order distortions (eight) shown in this figure is quite large compared to the "nearly-qwerty" layouts considered in this disclosure. Nor does this layout obey other order-constraints, such as the keyboard-name constraint, which will be discussed in detail below.

The 5-column qwerty keyboard of Fig. 4C is an even-as-possible qwerty-like keyboard. This layout was used by US. Pats. 5661476 and 6295052 in a non-ambiguous way. As just mentioned, the use of ambiguous codes for qwerty-like keyboards (including even-as-possible and non-even-as-possible) was pioneered by Gutowitz '863, and used in a commercial setting by Research In Motion, in their model 7100x phones. This even-as-possible layout represents a severe partition constraint and thus leaves an insubstantial margin for a trade-off with typability constraints. As will be discussed below, the 5-column design allows for layouts of much higher typability than the even-as-possible layout of Fig. 4C.

Even-as-possible qwerty-like ambiguous keyboards and appearance distortion

Gutowitz '863 covers both even-as-possible and non-even-as-possible ambiguous keyboards. Even-as-possible is a base from which appearance distortion can be measured. Intuitively, even-as-possible ambiguous keyboards have relatively low appearance distortion since the conventional keyboard on which they are based is trivially even-as-possible since each key has exactly one letter. To be qwerty-like, a reduced keyboard should preferably a) have the same letters in each row as qwerty, and b) have a monotonically decreasing number of keys with letters, as the row increases from top to bottom. Some sample even-as-possible keyboards with varying number of columns, and monotonic decrease are shown in Fig. 14.

Since there are one or very few even-as-possible layouts for a given number and arrangement of keys, optimization for typability over the set of even-as-possible layouts is trivial. The difficult problem, recognized and then solved by this invention, is to limit distortion at a non-trivial level, and then optimize typability while respecting that limit. As long as the distorted keyboard remains a small perturbation from the conventional keyboard, consumers may be expected to accept the keyboard. The trick is to maximize typability even though the perturbation remains small. As can be seen from Fig. 14, the first even-as-possible layout which achieves even the minimal level of touch typability (Level A touch typability of Gutowitz '863) is the 4-column layout. It would be of significant importance to achieve touch typability with a 3-column keypad, as such keypads are extremely wide-spread. This issue will be returned to below.

Methods

In this section we will discuss the two major properties with which this invention is concerned: typability and distortion.

Typability

Typability refers to properties which affect the throughput of text when an ambiguous keyboard is used to enter text. How many keystrokes are required per character? How many errors does the system make? How does it respond when a user makes an error? Typability properties have their origin in the interaction of the keyboard with the disambiguation software. To review, a typable device based on an ambiguous code has three main elements. Referring to Fig. 7, we see a block diagram outlining these elements. The ambiguous keyboard **701** sends keystrokes to the disambiguation software **702**, which does as well as possible to decode keystroke sequences as text, which it sends to an output **703**.

There are many factors which affect throughput of text through the device outlined in Fig. 7. Some of these are listed in the chart of Fig. 8. Some factors are related to the keyboard only, e.g. the difficulty of pressing a key, and some factors are related to the disambiguation system only, such as, in a dictionary-based system, the number of words in the dictionary. We will be often concerned with properties which arise from the interaction of keyboard and disambiguation system, such as lookup error. Lookup error is the rate at which a word-based disambiguation system will guess the wrong word, a word not intended by the user, but which has the same keystroke sequence as the word intended by the user. This property depends both on the disambiguation system and on the keyboard layout.

To help appreciate how keyboard layouts relate to typability, we will quickly review character-based and word-based disambiguation methods and measures of their typability. This material is covered in more detail in Gutowitz US Pat. No. 6,219,731, and Gutowitz '863, both hereby incorporated by reference and relied upon. In particular, Gutowitz '863 defines several measures of typability for word-based disambiguation systems, notably lookup error, query error, effective key number, and levels A, B, and C of touch typability. A disambiguation system

with an effective key number of n has the same performance as the best that can be achieved on keyboards with n letter keys, if the letters can be arbitrarily assigned to keys to maximize typability. In all of the cases we will consider here, letters cannot be assigned arbitrarily to keys. Indeed, our concern here is with layouts under tight constraints to be as close as possible to a given layout. Thus the effective key number of the layouts we will discuss will be much less than the number of letter keys they possess. The relationship between effective key number and levels A, B, C of touch typability is shown in Fig. 9, taken from Gutowitz '863.

For character-based prediction, a more relevant measure of typability is keystrokes per character. In these systems, the user presses a key, and then a Next key is used to advance the order of letters assigned to the key, in order of likelihood given the previously defined context of other input letters. In Gutowitz '731, the present Fig. 10 was presented, which shows the expected keystrokes per character as a function of the position of a letter in a word. This is done for two systems, the standard non-predictive multi-tap system available on essentially all cell phones, and the predictive character-based disambiguation of Gutowitz '731.

Word-based and character-based disambiguation are but aspects of the more general framework of context-based disambiguation, as discussed in Gutowitz '863. Each sub-type of disambiguation may have a corresponding typability measure which is best applied to it. In particular, and as was pointed out in Gutowitz '731, it is obvious even to one poorly skilled in the art to add word completion or phrase completion to any existing text-entry method without word completion or phrase completion. If word completion or any other feature is added to an existing text-based method, then the quantitative measures described herein also need to be modified to take account of the new feature, a modification which would not escape the scope of this invention.

1.0.1 Measuring and Modeling Distortion

Throughout, we will use the qwerty keyboard as an example conventional keyboard. It should be evident that the discussion applies as well to any other conventional keyboard. The conventional qwerty keyboard is characterized as having

1) 1 letter per key 2) monotonically decreasing number of letter-assigned keys as the row varies from top to bottom.

The minimal distortion keyboard will have a distribution of letters over the keys which is as close to this as possible. The maximal distortion keyboard will have a distribution of letters over the keys which is as far from this as possible.

In general, we could consider layouts with different numbers of letter assigned keys in each row. But to simplify the present illustrative discussion, let us make the further restriction that each key in the 3x3 array has at least one letter assigned to it.

The next step is to assign a numerical measure to a quantum of distortion. There are various ways of doing this. To be effective, the measure chosen should be a good model of the perceptual or interactive constraint to be optimized. It will be appreciated by one skilled in the art of mathematical modeling that the model and the phenomenon must be distinguished. In the case of appearance distortion, the phenomenon is psychological: to what degree are the reference conventional keyboard and the distorted keyboard perceived as similar? A person skilled in the art of scientific method would know how to measure this phenomenon in the laboratory, and a person skilled in the art of mathematical modeling would know how to build a mathematical model of the phenomenon. From the mathematical model, the calculations used to perform the distortion minimization called for can be made more rapidly than by direct pyschological research. Similarly, scientific observation of human interaction with keyboards, measurements on the anatomy and physiology of the hand, and so on lead a person skilled in the art of scientific

method to develop a description of gestures used in typing. Indeed, there is a large body of literature on this subject. From these experiments and literature, a person skilled in the art of mathematically modeling can develop a model of gesture distortion. The models discussed in this disclosure, and the resulting optimized keyboards, are non-limiting examples chosen for their ability to teach the person skilled in the art how to make and use distortion limited and typability optimized keyboards.

To illustrate, we will now consider some variant numerical models of the intuitive "looks as much like the qwerty layout as possible".

Let us consider two measures:

1) D= distortion = the sum over all keys of the number of letters on the key-1.

2) D= distortion = the sum over all keys of the number of letters on the key squared.

Two extremes are illustrated in Fig. 13. The distortion, D, of the Fig. 13A is 17 according to measure 1) and $18^2 + 8 * 1 = 332$ according to measure 2). There are 8 other layouts with the same distortion, the layouts with the maximum number of letters on key 2-9, and one letter per key on the others. The other extreme in terms of evenness is shown in Fig. 13B, which has 3 letters per key, except for one key with 2 letters. According to measure 1) Fig. 13B has a distortion of $8 * 2 + 1 = 17$, and according to measure 2), the distortion is $8 * (3^2) + 2^2 = 76$. In other words, measure 1) does not distinguish between Figs 13A and 13B in terms of distortion; each of Figs. 13A and 13B have the same numerical value of distortion (17). And yet, to most people, Fig. 13B is more qwerty-like than Fig. 13A. This suggests that measure 2) is a more correct representation of the perception of qwerty-likeness than measure 1. Measure 2 gives a lower value of distortion (76) to Fig. 13B than it does to Fig. 13A (332).

By measure 2), Fig. 13C has value 78, greater than the value 76 for Fig. 13B. And yet, Fig. 13B looks less qwerty-like than Fig 13C. The reason is that in Fig. 13B several letters are not on the same row as they would be in a full qwerty

keyboard, whereas in Fig. 13C, they are. This suggests modifying the measure to penalize for letters not in the correct row, e.g.

$\sum_{keys} L_{key}^2 + 5 * \sum_{letters} G(l)$ where L_{key} is the number of letters on a key, and $G(l)$ is 1 if the letter l is not in the same row as it is in qwerty, and 0 otherwise. This would give us the values 402, 96, and 76 for Figs. 13A, 13B and 13C respectively. This is a better ranking of these layouts, as it accords better with our perceptions of distortion.

It is to be stressed again that the measure used here is meant as an illustrative example. It has the advantage of being simple and of seeming to correctly order these keyboards by their intuitive perceptual distortion. Any reasonable (in the sense of agreeing with reality) distortion measure could be used in its place.

Psychological testing could be done to determine a functional model which is more in accord with human perception than the simple model considered here. A more accurate model would not change the scope of the invention, only the numerical values assigned to keyboard layouts. In such a psychological test, various layouts would be presented to a large number of subjects a large number of times, and the participants asked to chose from a set of layouts those that they thought were more qwerty-like.

In general, we can distinguish (at least) two classes of layout properties which might be building blocks of a quantitative model of human similarity perception: partition-related properties and order-related properties. Some illustrative partition-related properties are listed in Fig. 11, and some illustrative order-related properties are listed in Fig. 12. The partition properties have to do with the distribution of letters over keys. Whereas the order-related properties relate to where each letter stands in the conventional ordering of letters as expressed in a conventional layout.

We will now more briefly review some exemplary constraints which may be applied using the teachings of this invention to design useful keyboards. In view of this disclosure, it should be evident how to apply these or other constraints to

optimize typability while respecting the constraints.

The first set of constraints apply to appearance distortion. The second set of constraints apply to gesture distortion. We will consider various exemplary embodiments displaying combinations of these constraints with various interaction mechanisms and typability measures.

These varied examples are meant to show that any given set of distortion constraints or typability measures can be combined according to the teachings of this invention. These examples are chosen to illuminate various facets of the invention. Under this light, intermediate or hybrid designs should be clearly seen by a person skilled in the art.

Partition Distortions

Exemplary partition distortions are shown in Fig. 11. These properties are related to the visual balance and harmony of the keyboard. For instance, the range of the partition, the difference between the maximum and minimum number of letters on a key, describes an evenness property. An advantage of partition-related properties is that they are easily measured aspects of a layout. Whether or not the aspect is important to the psychological perception of similarity is a matter for psychological testing. From the standpoint of this invention, what is important is that a person skilled in the art could use these or other quantities as a means to development a mathematical model. The model, in turn, could be used for a basis for sifting through the space of alternate layouts to try to identify those which are best according to the essential factors identified here: typability and distortion. In the illustrative embodiments presented below, we will consider how some of these quantities can be used to produce useful keyboards. Upon contemplation of these illustrations, the person skilled in the art will be able to use other measures, singly or in combination, to select keyboards with good typability and appearance properties.

Order Distortions

An order distortion is a change in the order in which symbols are read from the keyboard. To define this, we must establish the conventional reading order for the keyboard. Natural written languages generally have a preferred reading order, and the keyboards used to write the language inherit the reading order. English is read from left to right, top to bottom, and the qwerty keyboard is generally read the same way. The name "qwerty" comes from reading the first six letters of the keyboard. A Hebrew keyboard would be read right to left.

There are exceptions. The Dhiatensor keyboard of Figs. 3A and 3B is read from left to right, bottom row to top row, giving rise to the name "Dhiatensor" (the first letters in the reading order). The "abc" keyboard of the standard ambiguous code, is read left to right, top row to bottom row. A given keyboard may admit multiple readings, as evidenced by multiple names. The dominant convention for the "qwerty" keyboard is left to right, top row to bottom row. However, it was proposed (Neuman, Alfred E. 1964) to read the keyboard right to left, top row to bottom row, resulting in the name "poiuyt". Were this proposal to become conventional, then, by the teachings of this invention, these letters should be conserved in that order, in addition to or instead of "qwerty". The half-qwerty keyboard of Fig. 6 can be read both in the qwerty and the Neuman order.

Fig. 12 gives a chart of some illustrative appearance order constraints related to order. Some of these will be used to develop embodiments of the invention below. Each constraint could be a component of a model to quantify perceived distortion. For instance, research suggests that if the first and last letters of a word are correct, but letters in the interior of the word are changed, then people can still read the word with high probability. If the same property holds for reading of conventional keyboards, then a model might give higher weight to changes which occur at the borders of the key layout than changes to the center.

Gesture Distortion

Gesture distortion is important for those who actually use keyboards, rather than simply look at them. Anyone trained to touch type on qwerty who tries to touch type on a close variant such as the azerty keyboard used in France (Fig. 4B) will be familiar with the effects of gesture distortion. Since some of the letters have been moved from their "correct" position, the gestures used to type those moved letters no longer give correct results. Azerty touch typists experience the same effect when they try to use a qwerty keyboard. The distortion of azerty with respect to qwerty is both an appearance distortion and a gesture distortion. On an ambiguous keyboard, it is possible to distort appearance without distorting gestures. For instance, on the standard telephone keypad, the letters A,B and C are assigned to key 2. Typing any of these letters involves the same gesture: reaching for the 2 key. If the key were to be labeled CBA, with the letters in reverse alphabetic order, then the appearance would be changed, but not the gestures.

Optimization with respect to gesture must take into account not only the appearance of the keyboard, but the way in which the user interacts with the keyboard. The style of interaction will be referred to as the interaction mechanism. A chart of illustrative gesture distortion constraints is shown in Fig. 15.

How much gesture distortion is acceptable?

Azerty is initially somewhat difficult to touch type for a qwerty typist, and yet azerty is initially perceived to be similar enough to qwerty to be used by a qwerty typist. By contrast, everyone recognizes immediately that a Dvorak cannot be touch typed by a qwerty typist without training. This suggests that there is some non-zero threshold of appearance distortion which is permissible without losing the interest of inexperienced consumers. The goal of one aspect of this invention is to use this small margin to introduce improvements in typability. It cannot

be over stressed that most commercial failures of prior-art innovations are due to their failure to recognize, let alone obey, this distortion limit.

In the azerty-qwerty distortion, there are 5 letters which are displaced. All of these are changes which involve equi-finger or near-equi-finger movements. Four of the letter movements are be expressed as two swaps. A rule of thumb might be that 5 significant gesture changes are an upper bound for allowed gesture distortion, if the keyboard is to be used immediately without training (possibly with typing errors). Psychological research would be required to give a better bound than this one, gleaned from contemplation of the prior art.

Symbolic representation of distortion

Recall that the problem to be solved by this invention is to minimize the negative impact of distortion on consumer appetite for new keyboard products. A substantial realization is that a distortion may be better assimilated, and thus minimized, if it can be simply symbolically expressed. The simple symbolic expression allows the distortion to be explained, remembered, compensated for, with ease. The simple expression reduces the apparent complexity.

A well-known method in computer science to measure the complexity of an object is the length of the shortest program needed to compute the object. Distortion can be measured in the same way. The description is a set of words sufficient to allow someone knowing those words, along with any conventional knowledge well-known to those skilled in the art, to find each and every letter on the keyboard. Imagine a sales person explaining the new keyboard to a potential customer, e.g. "It's like qwerty, but a and z are reversed" might describe a first keyboard, and "It's like qwerty, but a is moved two keys to the right, r is moved two keys down, t is moved two keys to the left and one key down" might describe a second keyboard. In this case the first keyboard is less distorted than the second, since the first has a shorter description.

Related to description length are other methods to symbolically represent distortions. Mnemonics may be useful, as could be the association of the distortion with a known word, sound, or object. Indeed, any know memorization method might find a role in expressing a distortion in a way which makes it more palatable to a consumer. Several possible symbolic representations of distortion and their use in designing keyboards will be discussed in the detailed description of embodiments of the invention below.

Method for making a typability optimized keyboard with minimized distortion

Referring to Fig. 16, a method is described for making a typability optimized keyboard with minimized distortion.

Step **1600**: select conventional keyboard layout

Step **1601**: select reduced spatial arrangement

Step **1602**: select distortion measure(s)

Step **1603**: select typability measure(s)

Step **1604**: Evaluate the (typability, distortion) measures for a set of layouts

Step **1605**: Select layouts which optimize typability while respecting distortion limits

In the set of embodiments below, this method will be carried out in a variety of circumstances, under a variety of design constraints, to illustrate its wide applicability.

Best Modes

Fig. 17 presents a chart giving an overview of the embodiments to be presented in detail below. Each embodiment is chosen to highlight one or more facets of the present invention, and to thus map out its scope. Upon assimilating the

teachings of these embodiments, it will be clear to one skilled in the art how to construct intermediate and hybrid cases, and otherwise depart from the letter of this disclosure without departing from its spirit.

Practical Qwerty-like keyboards for cellphones

This embodiment is meant as an illustrative example of how the teachings of this embodiment could be applied in a real-life engineering situation, in which several constraints may be simultaneously operative. It will show how various tradeoffs between typability and distortion can be managed to meet industrial specifications.

Here, the desire is for a phone which is typability maximized and appearance distortion minimized. It is agreed to measure appearance distortion in the following way:

1) Only number keys (0-9) of the standard telephone keypad may be used for letters.

2) The reading order of qwerty must be conserved as well as possible, beginning at the left. In particular, the name "qwerty" must be at the beginning of the top row, with all of the letters in order.

3) No more than 4 letters on any key. This constraint is due to practical limitations on the number of letters which can be incorporated in a key label, given the small size of the keys, as well as in the belief that such a partition limitation will reduced apparent distortion.

4) The description of the keyboard in the users manual in English must be as short as possible, and easy to remember. This constraint is adopted both in view of the cost of producing users manuals, and in the belief that it will reduce effective appearance distortion.

Referring to Fig. 18, we see that one method to find a solution for these requirements is to:

Step **1801**: Maximize typability using only row- and order- preserving transformations.

Step **1802**: Select a subset of layouts which a) have the best typability, and b) have no more than 4 letters on a key.

Step **1803**: Distort each layout from step **1802** in all possible ways by moving 1,2,...,n letters from their original position, placing them on the right of the keyboard, or on the 0 key. To preserve initial reading order, do not move letters to or from the left column of the keyboard, or any of the letters q,w,e,r,t,y.

Step **1804**: Select from the layouts of step **1803** those which have a) high typability, b) short, easy-to-remember descriptions.

It will be appreciated that the problem can be approached in other ways, such as using a stochastic optimization technique such as simulated annealing or genetic algorithms. This procedure has the didactic advantage of bringing out the interplay of distortion and typability optimizations, and is easy to execute in practice.

Step **1801**: maximize typability using only row- and order- preserving transformations. This can be accomplished e.g. using any of the methods described in Gutowitz '863. Our first goal here is to study the relationship between layout range and typability. For equal typability, lower layout range is preferred. To accomplish this, we will optimize typability (here, measured by effective key number) for each of a set of layouts in which the layout range is fixed at 1 through 7.

The results of applying this step are shown in Figs. 19 and 20. In Fig. 19 the effective key number of the best layout found for each min-max range from 2 to 7 is shown as a function of the range. For guidance in interpreting these results, several horizontal lines are drawn. Reading from bottom to top, these lines give:

a) The effective key number of the even-as-possible code qwerty-like code on three columns. The layout of the even-as-possible code is shown in Fig. 14.

b) The effective key number of the Standard Ambiguous Code (SAC), that

is, the "abc" code of a conventional telephone keypad.

c) The minimum effective key number for Level A touch typability as defined by Gutowitz '863.

d) The effective key number of the best possible code on 9 keys, allowing an arbitrary assignment of letters to keys.

e) As in d), but for a 10-key code.

The layouts corresponding to the points plotted in Fig. 19 are shown in Fig. 20, where the layouts with range 2-7 are shown in Figs. 20A to 20E respectively.

We note that these results indicate that there is no advantage in terms of typability to consider ranges above 4. Increasing range not only increases the distortion, but also seems to decrease typability. For further work on this problem, then, we can confine ourselves to the study of layouts with range 4 or less.

Note that the curve of best layouts never passes the line of Level A touch typability. This experiment thus suggests that it is not possible to obtain a touch typable code on the telephone keypad if row and order constraints are completely respected. Still, partition distortion alone is sufficient to substantially increase typability above the base level set by the even-as-possible code.

Step **1802**: Select a subset of layouts which a) have the best typability, and b) have no more than 4 letters on a key.

Satisfaction of this requirement emerges from the observation just made that large range reduces typability. In this case, the explicit distortion limitation and a limitation to increase typability are coherent with each other. We will see that in general that is not the case: increase in allowed distortion increases the level of typability which can be achieved.

Step **1803**: Distort each layout from step **1802** in all possible ways by moving 1,2,...,n letters from their original position, placing them on the right of the keyboard, or on the 0 key Do not move letters from the left column of the keyboard, or any of the letters q,w,e,r,t,y.

Having done as much as possible with partition distortions, step **1803** explores

the effect of adding small amounts of order distortion. The order distortions are limited in the hope of minimizing the perceived distortion.

The results of this step are shown in Fig. 21. Here the distribution in effective key number of the layouts generated with 1 through 4 order distortions is shown. It is seen that the distribution of effective key number becomes broader as the number of order distortions increases. Though the average effective key number remains approximately the same as the number of order distortions increases, it becomes possible to find layouts with better and better (and worse and worse) effective key number in the extremes of the distribution.

In step **1803** letters were allowed to move onto the 0 key, thus violating both row and order constraints, and potentially increasing the number of letter keys to 10. It also allowed for all of the letters on some key to move to other keys, reducing the total number of letter keys. Thus, Fig. 22 shows three curves, one for each of 8, 9, and 10 letter keys. The effective key number of the best layout for the given number of order distortions and the given number of keys is shown in these curves. The horizontal lines are the same as those of Fig. 19, with the addition of a line giving the effective key number of the even-as-possible code on 5 columns. This even as possible code on 5 columns is shown in Fig. 14.

It is seen in Fig. 22 that with order distortion, it is possible to achieve touch typability of Level A from a telephone key, with 9 or 10 letter keys, though not with 8. Indeed, with 10 letter keys, a level of touch typability substantially the same as the 5-column even-as-possible layout is possible, with as few as three order distortions. But is three order distortions an acceptably low level of appearance distortion? How can the visual impact of these order distortions be muted? This is addressed in the next step of the procedure.

Step **1804** From the layouts of step **1803** select those which have

- high typability, and
- a short description length,

- an easy-to-remember description.

To negotiate this tradeoff, we first attack the constraint of short description length. To quantify this constraint, we will consider layout descriptions of the form: "It has the qwerty layout, except: [itemize exceptions]."

Any distorted qwerty keyboard could be described in this format. The length of the description is related to a) the number of exceptions, and b) the compactness with which the exceptions can be expressed. The typical exception would be written: "except the letter x is on the 0 key".

Note that if two letters are moved to the same key, then two exceptions can be expressed without doubling the number of words, e.g. "except the letters xy are on the 0 key".

It would be easier to remember such a rule if the letters were not arbitrary, but pronounceable, or better, spelling a word, such as "lu" or "gum", e.g. "except 'gum' is on the 9 key". This has the same content as the item "except the letter g is on the 0 key and the letter u is on the 0 key and the letter m is on the 0 key", but is easier to remember.

A promising candidate according to these considerations is the "qwerty-glu" layout of Fig. 23, and marked as the point "GLU" in Fig. 22.

This layout has three order distortions. The letters g, l, and u are not in their qwerty positions. They are moved to the end of the layout. The main part of the layout can thus be read without insertions, only deletions, and the deleted letters reappear at the end of the reading order. The letters "glu" are pronounceable, appear in the order in which they are pronounced, and form part of an easy-to-remember mnemonic, "qwerty GLUed onto a cell phone". The effective key number is very close to the maximum which was achieved in this experiment for any layout with three order distortions.

It should be evident to one skilled in the art that this procedure permits many variations while remaining within the scope of the invention. Different

constraints could be used. The steps could be performed in a different order or steps omitted. A different basic convention could be used other than qwerty. A different keyboard geometry could be used, and a different mnemonic employed.

Application of the method to 5-column qwerty

It should be evident that the method explained above for finding a qwerty-like keyboard of optimized typability and minimized distortion for a telephone keypad can be modified to apply to many situations. In this section we will quickly examine the result of applying the method to building a layout for a 5-column qwerty-like keyboard. While in the case of the telephone keypad, work was needed to find acceptable keyboards with Level A touch typability or better, in the case of 5 columns, Level C and beyond is attainable, using minimal order distortion.

Turning now to Fig. 24, we see the results of applying the method of Fig. 18 to a 5-column qwerty-like keyboard. This figure is essentially the same as Fig. 22, except now applied to 5-column rather than 3-column qwerty-like keyboards. Since the effective key numbers in question are higher, we are able to consider the relationship of these keyboards with higher levels of touch typability, namely levels B and C of Gutowitz '863. While the even-as-possible keyboard on 5 columns has typability between levels A and B, with only partition distortions, and no order distortions, it is possible achieve greater then level C touch typability. As the number of order distortions increases, the level of touch typability increases as well, as can now be expected from the results just presented for 3-column keyboards.

Turning now to Fig. 25, we see details on each of the layouts corresponding to a point on the curve of Fig. 24. For comparison, Fig. 25A shows again the even-as-possible keyboard on 5 columns. Figs. 25B to 25E show keyboards with increasing amounts of order distortion. The letters displaced are (none), (u), (di), (diu), (lguh) for Figs. 25B to 25E respectively. It is worthwhile noting that Fig.

25B, with no order distortion, might be perceived as more appearance distorted that Fig. 25C, which has one order distortion. Fig. 25B has a greater range, as the largest number of letters on a key is 4 and the smallest is 1, giving a range of 3, whereas in Fig. 25C, the largest number is 3 and the smallest is 1, giving a range of 2. It may be therefore, that psychological testing would show Fig. 25C to be less distorted than Fig. 25B. In the case of Fig. 25C, a simple mnemonic is available to aid in remembering the distorted layout, "yoU to the center".

A simple-to-remember Two-Key Keyboard

Perhaps the simplest-to-remember keyboard is one in which all letters are on the same key. In some sense, it is compatible with any convention, and the association of letters to keys is trivial to remember. Unfortunately, one-key keyboards have rather poor typability properties, regardless of how these properties are defined.

The next step toward a full keyboard is a two-key keyboard. At this step already, there are challenging problems for designing keyboards which are both easy-to-remember, compatible with convention, and have good typability properties. This invention shows how to overcome these challenges. The two-key problem has important industrial applications. Many electronic devices which could benefit from text entry do not have a keyboard with even as many keys as a telephone keypad. A typical example is a digital camera, comprising a navigation keypad. Such a keypad typically has two or more arrow keys. These could be used for text entry, if only a sufficiently accurate, sufficiently learnable method were available for such a small number of keys. Text entry would be useful, e.g., to annotate the photographs.

We will now present several embodiments of the invention which solve the two-key problem, in a way which serves to amplify and enforce the teachings already disclosed.

Fig. 26 non-limitatively illustrates a typical navigation keypad. Here there

are four arrow keys, are typically associate with movement left **2601**, up **2602**, right **2603** and down **2604**. The center key **2605**, is typically associated with the actions "accept" or "advance".

We will consider several approaches to using such a navigation keypad to enter text, all rather different from each other, yet all within the scope of this invention. These are:

- Conservation of alphabetic order.
- Conservation of qwerty gestures.
- Use of a purely symbolic method, independent of any layout convention.
- Row conservation from the telephone keypad.

Fig. 27 shows a three-key system with two letter keys, and one Next key. The Next key would be used to advance letters in a character-based disambiguation system, and words in a word-based disambiguation system. In this illustration, the alphabet is split in half, with one half on the letters on each of the letter keys. Other choices are possible, as will be discussed below. A likely association of these three keys with the navigation keypad of Fig. 26 would be to associate the letter keys of Fig. 27 with two of the arrow keys of Fig. 26, and the Next key with either another letter key or the "accept" key.

Fig. 28 shows an alternate two-letter arrangement for a navigation keypad in which the letters of the left half of the qwerty keyboard are associated with the left letter key, and the letters of the right half of the qwerty keyboard are associated with the right letter key. Fig. 28A shows the layout conceptually, and Fig. 28B shows the qwerty layout superimposed on the two keys. This keyboard has an advantage for experienced users of reduced qwerty keyboards using a two-thumb interaction method. The gestures of the thumbs are nearly the same, except that in the navigation keypad version, movement of the thumbs between keys is not required.

It is possible to design keyboards which optimize with respect to description length, without regards to appearance or gesture distortion. As a non-limiting example, consider the 2-letter-key layout of Fig. 29. In this keyboard, all of the consonants are assigned to the left key, and all of the vowels are on the right key. This last sentence describes the keyboard sufficiently to allow someone who knows the meaning of the words consonant and vowel to locate all of the letters on keys. This keyboard is thus easy to explain and to remember, exemplifying one aspect of the present invention.

We have already pointed to the advantage from the point of view of appearance distortion to minimizing row distortions. Letters in the distorted keyboard should, if possible, be in the same row as the conventional keyboard to which the distortion is related.

Turning to Fig. 30, we see a navigation keypad in which three arrow keys are used as letter keys. The letters associated to each of the keys are those of a row of the standard telephone keypad. The letters A-F **2608** correspond to (ABC,DEF) on the telephone keypad, G-0 **2606** correspond to (GHI,JKL,MNO) on the telephone keypad, and P-Z **2607** coresond to (PQRS,TUV,WXYZ) on the telephone keypad. This keyboard could appeal to those with advanced experience in typing on a telephone keypad. The gestures used to type on the navigation keypad so constructed are similar to the gestures used for typing on the telephone keypad. Due to this careful conservation of the letter-to-row association, the keypad is easy to explain to those familiar with the telephone keypad.

One way by now familiar to readers of this disclosure to evaluate the typability of these various two-key embodiments would be to measure their keystrokes per character, effective key number, or other property related to the disambiguation mechanism. We will consider below the application of some new techniques to this situation.

A method to predict which two-key approach is better

We have discussed description length as a measure of complexity used in computer science, and shown how it can be applied to measure appearance distortion. Another way that the complexity of an object is conceptualized in computer science is as the running time of the shortest program which computes the object. This complexity measure is also relevant to keyboard design, and could be used to estimate the acceptance by the marketplace of the various two-letter-key embodiments presented above.

The two-letter-key variants of qwerty, alphabetic, and vowel-consonant might seem to be roughly similar in terms of description complexity. One might guess on this basis, that they would all have roughly equal chance of success in the marketplace. To predict this accurately, one need to study how well the complexity measure agrees with the perceptions of actual human buyers. It is perhaps the case that the consonant/vowel keyboard would be judged easier than the split alphabetic keyboard which is in turn easier than split qwerty. Still, those users well trained in two-thumb typing on a miniature qwerty keyboard may prefer split qwerty.

While each of these descriptions correspond to short programs to compute the location of all of the letters, the running time of the program may be quite long. In the case of the split alphabetic keyboard, one may have to imagine reciting the alphabet, stopping at the desired letter, and checking whether they have already recited "m". This takes a certain amount of time. A person who knows the visual appearance of the qwerty keyboard could mentally scan the keyboard, searching for their letter. A person trained in *typing* two-thumb qwerty knows the location in the motor patterns of their thumbs. For example, on a 26-letter-key thumb-operated qwerty keyboard the motor pattern to type the letter Q is "move the left thumb to the key with Q , and press the key." To type on the novel two-key qwerty keyboard, the pattern is edited to "left thumb press the key". For the

two-thumb touch typist, then, the 2-key qwerty keyboard is easy.

Embodiment: Illustrative embodiment of gesture conservation with radical layout distortion

The embodiment of this section illustrates that gestures may be conserved even though the layout is radically distorted. The keyboard is meant to be used by drivers while driving, without causing them to remove their hands from the steering wheel. It is meant at the same time to leverage qwerty touch typing ability through conservation of gesture.

Turning to Fig. 34, we see a steering wheel **3401** into which a keyboard **3402** has been embedded or attached, preferably in a position which is comfortable both for typing and for steering.

To conserve gestures, in particular to make the distorted keyboard be equi-finger with the qwerty keyboard, all of the letters typed with each finger on the qwerty keyboard are assigned to the same key of the distorted keyboard. Thus the letters, q, a, and z, all typed with the little finger of the left hand using the qwerty keyboard, are all assigned to the same key in **3402**. Note that all of the letters r, f, v, t, g, b are typed with the same finger of the left hand, but each letters from each column of keys on the qwerty keyboard are assigned to different keys in **3402**. This increases gesture compatibility, as the figure must move from its home position to the right to type each of the letters t, g, and b on both the qwerty keyboard and the keyboard **3402**. The number of keys could be reduced further by joining these keys, with concomitant increase in gesture distortion and decrease in typability.

If the typability measure is effective key number, then the typability of either of these layouts is rather poor, however, given the teachings of this invention, it will be appreciated that typability could be improved if strict equi-finger or

equi-column gesture conservation is relaxed, e.g. by allowing movement of letters to adjacent fingers.

Though this keyboard was discussed in the context of a steering wheel embodiment, it could be useful in any device where the amount of space available for a keypad is limited, permitting only a line of keys. An example might be the edge of a pocket device such as a digital camera or mp3 player. It could be used in the handlebars of a treadmill or bicycle, etc.

The Drumroll Effect

When asked to press a single key repeatedly as fast as possible, humans typically are able to acheive 7 keystrokes per second. If a letter were entered with every keystroke, this rate would correspond to about 75 words per minute. However, sustained typing rates of 150 words per minute, with bursts up to 212 words per minute have been reported using a regular keyboard. Typing on a regular keyboard requires time to move the fingers from key to key in addition to the time required to press the key. Even ignoring the movement time, these typing speeds are much too fast to be consistent with the repeat time on a single key. Higher speeds can be achieved since while one finger is completing a key press, another finger is beginning another. Keystrokes may occur in parallel, if successive keystrokes are performed by different fingers. This is the so-called drumroll effect. The Qwerty keyboard is widely believed to have been designed such that common pairs of letters are typed with alternating hands, e.g. th, he, qu. We will examine this assertion shortly. Reportedly, this design was meant to minimize jamming of typebars. The maximization of left-right alternation had the (probably unanticipated) advantage for the touch typist of optimizing typing speed. A pair of left-right alternating keystrokes can be performed partially in parallel; the movement of second hand can be planned and executed while the motion of the first hand completes. Even on a single hand, different fingers can move more

or less in parallel.

Selecting a two-key layout on the basis of the drumroll effect

Above we considered description length, and mental computation time as means for predicting which two-key layout consumers would prefer. In this section we will make perference predictions based on the drumroll effect regarding these same keyboard.

Consider a simple model of the drumroll effect where the time to enter a pair of letters in sequence is 1 if the letters are on the same key, 1/2 if they are on different keys. Under this model, we can easily predict the time it would take for an expert to enter letters using any of the two-key embodiments discussed above. The results are shown in Fig. 32. In this figure, the inter keystroke time is evaluated for each of 26 alphabetic order variants **3201**. In each variant the letters before the given letter on the left key, and the letters after the given letter in order on on the right key. The minimum time is for letter number 10 (j). So we have the surprising result that dividing the alphabet at j results in faster times than any other division. A person skilled in the art but uninstructed in the use of the drumroll effect to evaluate keyboards would probably pick a letter more in the middle of the alphabet, such as m (as shown in Fig. 27). As can be seen in Fig. 32, this inter keystroke time is less than that of two-thumb qwerty **3202**. As another surprise, the lowest inter keystroke time of all is of the consonant-vowel two-key keyboard **3203**. Recall that the argument in favor of using the consonant-vowel keyboard for naive users was that a) unlike the qwerty layout, it does not require advanced experience of two-thumb typing on a reduced qwerty keyboard, and b) unlike the alphabetic keyboard, it does not require mental scanning of the alphabetic order. In this case, then, the criteria of acceptance by naive and experienced users seem to run in the same direction,

arguing for deployment of the consonant-vowel keyboard. Psychological testing would be required to confirm or contradict this prediction.

Optimization of the drumroll effect by minimizing steric hindrance

On very small keyboards, ambiguous or not, digits (fingers or thumbs) may share keyboard "territory" with other digits. When the digit size is large compared with the size of keys, then the presence of a digit on a given key may hinder the ability of another digit to occupy keys which are nearby. This effect is called steric hindrance.

This size effect complicates the analysis of drumroll effects considerably. Referring to Fig. 31, we see a sequence of increasingly small keyboards, capable of being typed with two thumbs. The relative sizes of keyboards and thumbs in this figure are suggestive of the relative sizes in the case of commercial handheld devices. It is seen that the amount of hindrance of one thumb by another depends sensitively on the keyboard size. For the relatively big keyboard, (Fig. 31A), when a first thumb is placed on a key, the second thumb can move to any other key which is not directly covered by the first thumb. At a smaller keyboard size (Fig. 31B), a thumb may hinder not just the key it is currently pressing, but also movement to surrounding keys. As the size becomes still smaller (Fig. 31C), the hindrance may extend to a large fraction of the keypad.

The drumroll effect relies on the ability of one thumb to be moved into position for its keystroke while the other thumb is performing its keystroke. With hindrance, one thumb must wait for the other to be displaced, after making its keystroke, if the target of the second thumb is in the hindered region of the first thumb. The hindrance may be complete or partial, depending on the keyboard size and geometry, and the pair of keys to be pressed in the drumroll.

The exact way in which digits hinder each other with respect to a given

keyboard depends on

- the interaction mechanism,
- the probability distribution of symbol sequences,
- the spatially distribution of the keys.

The final design of a keyboard to minimize digit hindrance will depend on how well known these factors are, and how well they are captured in a mathematical model. The present invention teaches the use of some model to measure hindrance.

For non-limiting illustration, we can consider a simple model of this potentially quite complicated situation as follows: Any key directly to the left of, above, or below the target of the left thumb will be considered completely hindered for the right thumb, and, similarly, any key directly to the right of, above, or below the target of the right thumb will be considered hindered with respect to the left thumb. The time for a hindered pair of letters will be considered to be the same as the time for two letters on the same key, and the time for an unhindered pair will be 1/2 of that time,

$t_{ave} = 1/(\#(i)) \sum_i T(l_i l_{i+1})$ where $T(l_i l_{i+1}) = r \; if \; (l_i l_{i+1}) \; hindered, \; r/2 \; otherwise$

and where l_i is a letter, $\#(i)$ is the number of letters in the string, and r is the time for a double tap on a single letter. This model is inspired by that of MacKenzie, I. S., & Soukoreff, R. W. (2002). A model of two-thumb text entry. Proceedings of Graphics Interface 2002, pp. 117-124. Toronto: Canadian Information Processing Society.

In short, any letter pair where the second letter is on the same or an adjacent key is treated as being effectively on the same key. In this case the double-tap time is used. If two letters are not on adjacent keys, then 1/2 of the double-tap time is used.

More advanced model would also take account of distance traveled by the fingers, in accord with Fitts, partial hindrance, and other more subtle effects.

Optimization of drumroll by multiplication of common symbols

It will be appreciated that the drumroll effect in the presence of steric hindrance can be optimized both by partition and order distortions, following the methods described above, and using a model such as the one presented above. Optimizations can also be made by modifying the physical structure of the keyboard. For example, keys could be spread out or changed in shape to increase the likelihood of a sequential pair of symbols being entered with a drumroll. We will now briefly discuss an embodiment which seeks to optimize the drumroll effect, particularly when steric hindrance effects are important, by multiplying the representation of selected symbols. The, symbol could be a frequent letter, such as the letter e in English, or a frequent punctuation symbol, such as the space symbol, or a frequently used functional symbol such as "Next" or "Shift".

The positions of the multiplied symbol are chosen such that, given the interaction mechanism, one or another representation of the symbol can often be input in a drumroll sequence, avoiding steric hindrance effects.

For word-based or character-based disambiguation without a shift key, one of the multiplied symbols is preferably "Next", since the Next function is often needed. When a shift key is used in disambiguation, such as in the embodiment discussed below, the shift key may be chosen to be one of the multiplied symbols.

Referring to Fig. 33, we see a telephone keypad **330**, with 9 alphanumeric keys **3300-3309**, and two Next keys **3311** and **3312**. The Next key is multiplied, that is, represented on more than one key.

The Next function is chosen to be multiplied in anticipation that character-based disambiguation will be used. In character-based disambiguation, the Next

function can be very commonly used, more often used than any letter or punctuation symbol. In Fig. 33, the keys on which to place the multiplied symbol are chosen in view of a two thumb interaction mechanism. Consider typing the letter "q" in a prior-art system in which there is only one Next key, say on the * key of Fig. 33. "q" is an infrequent letter, and so it is likely that the other letters on the key, p,r,s will be presented by the disambiguation system before "q", necessitating 3 presses of the Next key to enter "q". If the keys are small in relationship to the size of the thumb, then the sequence of keystrokes would be:

- press the pqrs key with the right thumb.
- move the right thumb to the Next key.
- press the Next key three times.

According to our model, This sequence will take 4 double-tap time units, plus the time it takes to move the right thumb from the pqrs key to the Next key.

If the keypad were larger, such that the left thumb could be moved to the Next key while the right thumb is on the pqrs key, then the following sequence of keystrokes could be used:

- press the pqrs key with the right thumb.
- press the Next key with the left thumb.
- press the Next key two more times with the left thumb.

The first two steps are combined into a drumroll, since they involve both thumbs so the second step takes 1/2 of the double-tap time. The total time is 3 1/2 double-tap time units.

On the keypad of Fig. 33, the sequence is:

- press the pqrs key with the right thumb.
- press the left Next key with the left thumb.

- press the right Next key with the right thumb.
- press the left Next key with the left thumb.

The time is 2 1/2 double-tap times, even if the keypad is very small. In this way, the multiplication of the Next key essentially eliminates steric hindrance as regards the Next key. It improves the throughput (number of symbols entered per unit time) even on large keypads, and has a more dramatic effect on small keypads.

In general, if only one symbol can be multiplied, given the number of keys available on the device, it should be the most frequently used symbol (functional symbol or otherwise). In the case of the hybrid chording/ambiguous code methods of Gutowitz '863, and the example below, the shift key is generally the best candidate to be multiplied, so that the shift key of the embodiment below could well be represented on both **3311** and **3312**. It should be evident that if the number of available keys is sufficient, then the 2nd, 3rd, ..., nth most frequent symbols could be multiplied as well, and that the position in the layout of these multiplied symbols should be chosen so as to minimize steric hindrance and maximize the drumroll effect.

Optimization for more than one interaction mechanism

The user population is not uniform. At one end there are risk-adverse users who only want something familiar even at the expense of typability, at the other those who value typability and are willing to invest in learning a new interaction mechanism and/or layout to obtain it. Yet, to obtain economies of scale, manufacturers prefer to make large numbers of a single product, and hope to appeal more or less well to everyone in a user population. One approach is to find the least

common denominator between the various groups of users. Another approach, the one taken here, is to simultaneously appeal to both the risk adverse and the typability avid. In some other embodiments of this invention, we have sought to make a single keyboard with a single layout which is simultaneously familiar and improved. Another approach to the problem is shown in the present embodiment, in which two keyboard layouts are simultaneously available, with only a change in software between them, and in which both are optimized as well as possible with respect to typability, but with a different interaction mechanism.

More particularly, we consider implementing a shifting and a shiftless layout on the same keyboard. The general method of doing this was discovered by Gutowitz '863, who showed how chording (or other means of combining keystrokes in a single gesture) could be used to optimize typability: in effect creating a new layout from an existing one by adding another shifted "dimension" to the layout. This same approach will be used here, with the distinction that the underlying layout is minimally partition distorted from a conventional layout. While this embodiment is fully within the scope of Gutowitz '863, it has the specific advantage of being minimally partition distorted from a conventional layout, so that both the underlying layout and the shifted layout are optimized for typability. This creates appeal across a broad spectrum of users, including those who refuse to use an unfamiliar shift mechanism, and those who relish that use, given that it provides greatly improved typability.

It will be appreciated that the interaction mechanisms chosen to be combined might be quite varied while remaining within the scope of this embodiment. In particular, 1-digit, 2-thumb, 3-finger, thumb + n-fingers, and 8-finger interaction mechanisms might be combined according to this invention.

To fix ideas, but without the intent of limitation, consider the following set of design specifications:

- The layout must be similar to qwerty in appearance.

- The layout must fit on a standard telephone keypad.
- For those who will not use a shift key, or are not able to since only one hand is available for typing, the keyboard must be typable, and must have typability no worse than the standard ambiguous code, assuming word-based disambiguation.
- For those who are able and willing to use a shift key, the typability must be as high as possible.
- A single layout must be used for both one finger without shift, and two thumb with shift interaction methods.

In order for the typability to be no worse than the standard ambiguous code, the effective key number must be no less than that of the standard ambiguous code, that is, 6.0. In order to limit appearance distortion, we may attempt to use as a base layout any qwerty-like layout for the telephone keypad with only partition distortions and such that the effective key number is at least 6.0. We may then consider all possible ways of shifting one letter from each of the keys on each of the layouts, and evaluating the effective key number of the shifted keyboard.

For comparison, we may also consider using one of the best telephone keypad layouts with order distortion, the qwerty-glu layout identified above, and again consider all possible ways of choosing one letter from each of the keys to be the shifted letter.

The results are shown in Fig. 35. On the left are shifted layouts derived from the non-order distorted layouts, and on the right, the shifted layouts corresponding to qwerty-glu are shown. Plotted are the effective key number of the base layout vs. the effective key number of each of the corresponding shifted layouts.

There are many interesting points in this set. The person skilled in the art could, in view of previous embodiments, chose one or the other depending on

further design specification. For instance, if the requirement is to favor typability of the shifted layout over typability of the base layout, and to avoid order distortion, then the layout **3501** may be chosen. This layout is more fully shown in Fig. 36. In the full view, the shifted letter on each key is shown in an italic font, whereas the unshifted letters are shown in normal font. Similarly, if the desire is to favor typability of the base layout over typability of the shifted layout, but order distortions are not permitted, then layout **3502**(Figs. 35 and 36) may be chosen.

If order distortions are permitted, then an improvement in the typability of both the base and the shifted layouts can be obtained, as seen in Fig. 35. There are many shifted layouts corresponding to each base layout. To select a single shifted layout from the set of shifted layouts corresponding to the base layout qwerty-glu, we may consider the economy of description constraint discussed above. The over-all best layout considering only typability is identified as **3503** in Figs. 35 and 36. We see that for layout **3503** the shifted letter is the last letter on each of the keys 1 and 7, and the first letter on each of the other letter keys. To minimize the description length, one may prefer a layout in which all of the keys have either the first or the last letter as the shifted letter. All keys with the last letter shifted is the layout **3504** of Figs. 35 and 36, and all keys with the first letter shifted is layout **3505** of Figs. 35 and 36. Unfortunately, in this case, short description length and typability are at odds. Between last letter on each key shifted and first letter on each key shifted, one may prefer first letter shifted, since capital letters are a) usually the first letter of a word (in English) and obtained by a shift using a standard full-sized keyboard. Thus **3505** would be preferred. However, **3505** has the lowest effective key number of any of **3503**, **3504** and **3505**. Layout **3504** is intermediate in terms of familiar description, and intermediate in terms of typability. **3503** is excellent in terms of typability, but requires more description. Comparing the shifted layouts of qwerty-glu to the shifted layouts corresponding to non-order-distorted layouts **3501** and **3502**

we see that, even though they have order distortion, they have less partition distortion (the range of qwerty-glu is smaller). Thus, one of the shifted relatives of qwerty-glu may in fact be perceived as less appearance distorted than the non-order-distorted layouts. Only psychological testing in which participants are asked to identify the layout they consider to be most qwerty-like could resolve this issue fully.

It will be appreciated that though throughout we have referred to "shifting" as a means to unambiguously identify one letter on each of the letter keys, any other known means could be used, such as double tapping for the shifted letter and single tapping for the unshifted letter, using a long press for one, a short press for the other, etc.

Predictive compensation for distortion

In the learning phase, when the user is making a transition between using the conventional keyboard and the novel, distorted keyboard, typing errors may occur due to mixing of conventional typing gestures with novel typing gestures. The effect is to make an unambiguous keyboard ambiguous, and introduces an additional ambiguity for keyboards which are already ambiguous.

Disambiguation software can be used to resolve many of these ambiguities. For instance, an azerty keyboard is a distortion of the qwerty keyboard for a person trained to type on qwerty. If such a person attempts to type English on an azerty keyboard, they will often type "zhat" since "what" is a frequent word in English, and the letters w and z are reversed in position from qwerty to azerty. Since "zhat" is not a common word in English, disambiguation software could be designed to automatically replace each occurrence of "zhat" with "what". While the basic idea is simple, practical difficulties arise in many instances. The user may have wished to type "zhat", perhaps as an abbreviation. In this case, replacing "zhat" with "what" would be an error. It may be difficult for the

disambiguation software to determine if "zoo" was typed correctly, or "woo" was meant, since neither is uncommon.

The same considerations apply to character-based disambiguation. For instance, the letter pattern "zz" is much more frequent in English than the pattern "ww", and yet it would be an error to replace www with zzz in a URL.

Like training wheels, disambiguation software can be an aid in the beginning of learning, and a hindrance later. It is thus desirable for the strength of distortion-compensation disambiguation to be adjustable. This can be accomplished in a variety of ways. The preferred way would be to compute the likelihood of a sequence both with respect to the conventional keyboard and the distorted keyboard, given the statistics of the language. This computation would be evident to those skilled in the arts of statistics and probability theory. Then, a user-adjustable parameter which sets a threshold such that sequences which are closer than the threshold in likelihood are not automatically rewritten, while when sequences are far apart in likelihood, and the conventional sequence is most likely, the distorted sequence is replaced with the convention sequence.

Referring to Fig. 37, we describe in more detail how this aspect of the invention performs.

Step **3701**: A likelihood threshold is set. This setting might be under user control, or might be set in hardware or software, perhaps on the basis of analysis of user behavior. The likelihood threshold determines the relative weight given to the conventional keyboard or the distorted keyboard interpretation of keystroke sequences.

Step **3702** A letter sequence K entered by user

Step **3703** software computes possibly intended sequence assuming both distorted and non-distorted keyboard.

Step **3704** If the sequence is significantly more likely when interpreted as typed on the non-distorted keyboard, then the non-distorted interpretation is output, otherwise, the distorted keyboard interpretation is output.

It should be appreciated that many variations are possible with respect to these illustrative embodiments without departing from the scope of the invention. In particular, making differences in natural language, conventional reference lay-out, keyboard geometry, distortion measure, hindrance measure, drumroll effect measure, or interaction mechanism are fully evident to one skilled in the art in view of this disclosure.

It is painfully obvious to those of even less than average skill in the art to use any of the above embodiments in combination with flourishes added to basic word or character-based disambiguation, such as a) word completion, b) phrase completion, c) a user dictionary, d) across-word prediction e) additional keys to input additional symbols (such as punctuation marks, short-cuts), indeed, any disambiguation mechanism can be improved via diligent application of the discoveries and techniques revealed in the present disclosure.

Therefore, the scope of the invention should not be judged merely from the superset of all possible combinations of aspects of these embodiments, but from the appended claims.

What is claimed is:

Claim 1. An apparatus comprising an ambiguous keyboard; keys for inputting symbols; said keys arranged in a substantially linear array; disambiguation software; said ambiguous keyboard characterized as minimized with respect to gesture distortion.

Claim 2. A method for making typability optimized keyboards with reduced distortion comprising the steps of selecting a conventional keyboard layout; selecting a reduced spatial arrangement; selecting a distortion measure; selecting a typability measure; evaluating a set of layouts by measuring said distortion measure and said typability measure for each element of said set of layouts; selecting a subset of optimized layouts from said set of layouts.

Claim 3. An apparatus comprising an ambiguous keyboard; said ambiguous keyboard comprising keys; a set of symbols; said symbols characterized as assigned to said keys, said symbols further characterized as divided into conceptually disjoint subsets, such that all of said symbols ambiguously input by said ambiguous keyboard are in one of said disjoint subsets; and an assignment of each of said disjoint subsets to one of said keys.

Claim 4. The apparatus of claim 3 further characterized in that said symbols are letters, and said disjoint subsets consist of the set of vowels and the set of consonants.

Claim 5. An apparatus comprising a single row of keys; and an ambiguous code; said ambiguous code characterized as being of minimized gesture distortion; where said gesture distortion is measured with respect to a conventional layout.

Claim 6. The apparatus of claim 5 said gesture distortion is evaluated on a set of gestures; said gestures drawn from the set of said gestures comprising an interaction mechanism; said interaction mechanism selected from the set comprising two-thumb and eight-finger interaction mechanisms.

Claim 7. An apparatus comprising a keypad with one to nine columns; an ambiguous code; said ambiguous code characterized as being of minimized appearance distortion with respect to both order distortion and partition distortion; said order distortion and said partition distortion evaluated with respect to a conventional layout; said ambiguous code further characterized as maximized with respect to typability.

Claim 8. The apparatus of claim 7 further comprising a second ambiguous code, said second ambiguous code characterized as a hybrid chording-ambiguous code.

Claim 9. The apparatus of claim 7 further characterized in that said appearance distortion is of minimized description length.

Claim 10. An apparatus comprising an ambiguous keyboard; said ambiguous keyboard inputting symbols; said symbols characterized as containing at least one symbol selected from the set consisting of functional and letter symbols; and where said said at least one symbol possesses a multiple representation on said ambiguous keyboard; said multiple representation characterized in that it minimizes steric hindrance.

Claim 11. The apparatus of claim 10 further characterized in that said multiple representation is of a shift function; said shift function characterized in that when it is activated substantially simultaneously with a key of said ambiguous keyboard, selected symbols assigned to said key are input.

Claim 12. The apparatus of claim 10 further characterized in that said multiple representation is of a next function; and that said symbols are arranged in an order; said next function characterized in that it advances said symbols in said order.

Claim 13. An apparatus comprising an ambiguous keyboard; symbols; keys for inputting said symbols; disambiguation software; said ambiguous keyboard characterized as optimized with respect to at least one typability constraint; and minimized with respect to layout distortion, said layout distortion measured with respect to a conventional layout.

Claim 14. The apparatus of claim 13 wherein said typability constraint is selected from the set consisting of lookup error, query error, effective key number, word-level ambiguity, word completion, phrase completion, drumroll probability, steric hindrance, throughput, robustness to typing error, language generality, fitts' law, and keystrokes per character.

Claim 15. The apparatus of claim 14 where said drumroll probability is optimized with respect to a two-digit interaction mechanism.

Claim 16. The apparatus of claim 13 further characterized in that said typability constraint is optimized with respect to at least one interaction mechanism.

Claim 17. The apparatus of claim 16 further characterized in that said interaction mechanism is selected from the group consisting of one finger, one thumb, two fingers, two thumbs, one finger and one thumb, three fingers, and eight fingers and two thumbs.

Claim 18. The apparatus of claim 13 further characterized as compatible with a telephone keypad.

Claim 19. The apparatus of claim 13 further characterized in that said ambiguous keyboard comprises three rows and 1-9 columns.

Claim 20. The apparatus of claim 13 wherein said layout distortion is selected from the set consisting of appearance distortion and gesture distortion.

Claim 21. The apparatus of claim 20 wherein said gesture distortion is quantified by a gesture distortion property; said gesture distortion property selected from the set consisting of same hand, same digit, same finger, and same thumb, nearby digit, and same gesture class.

Claim 22. The apparatus of claim 20 wherein said appearance distortion is a function of at least one layout property; said layout property selected from the set consisting of order and partition structure.

Claim 23. The apparatus of claim 22 where distortions to said order are quantified by a distortion property; said distortion property selected from the set consisting of reading order, row-limited reading order, column-limited reading order, exterior, row-limited, column-limited, number, and number of exchanges.

Claim 24. The apparatus of claim 22 where said partition structure is quantified by a partition property; said partition property selected from the set consisting of even as possible, maximum number of letters on a key, minimum number of letters on a key, range, dominant class size, left-right symmetry, up-down symmetry, and monotonicity.

Claim 25. The apparatus of claim 20 wherein said appearance distortion is measured as a distortion relative to said conventional layout, and said conventional layout is selected from the set consisting of telephone keypad, qwerty, qwerty national variant, and unicode script conventions.

Fig. 1/37

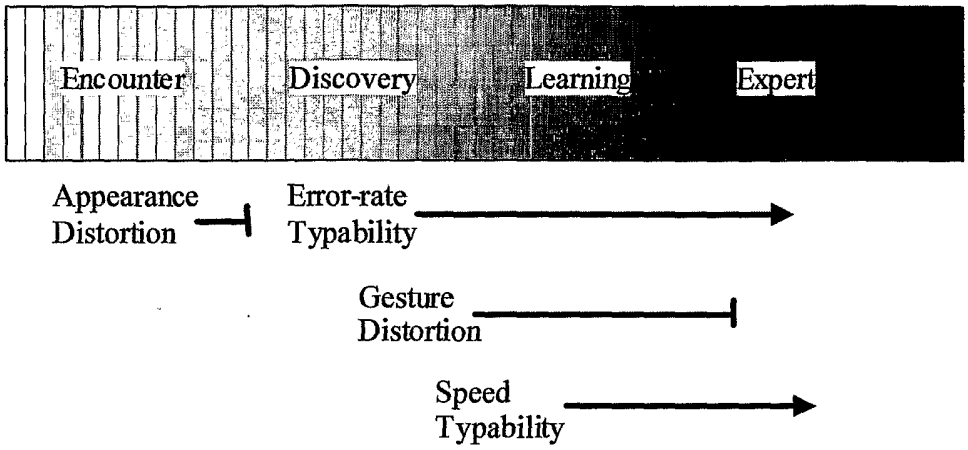

Encounter
Discovery
Learning
Expert
Appearance
Distortion
Error-rate
Typability
Gesture
Distortion
Speed
Typability

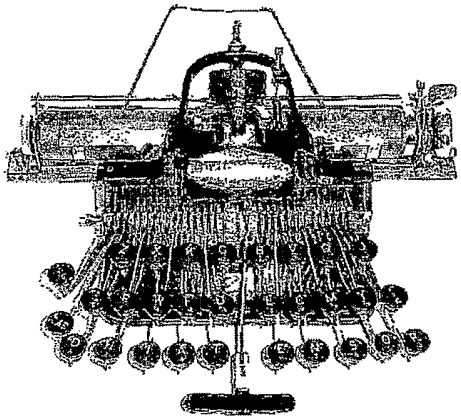
Fig. 2/37

Name	Brief Description
Qwerty	Archetype of a conventional keyboard. For latin script languages. Fig. 4A.
Azerty	Qwerty variant conventional in France. Fig. 4B.
Cyrillic	A conventional keyboard for Cyrillic script languages. Fig. 4D.
Dhiatensor	Typability optimized for 2 finger interaction. Not ambiguous code. Not drumroll, No distortion minimization. Fig. 3A, Fig. 3B.
Dvorak	Typability optimized for 8 finger interaction. Not ambiguous code. Not drumroll, No distortion minimization. Fig. 3C.
Half-qwerty	Gesture distortion optimized, with radical appearance distortion. Not ambiguous code. Fig. 6.
Gutowitz '05	Introduces even-as-possible and not-even-as-possible qwerty-like. Introduces both order-preserving and non-order preserving distortions, but no explicit limitation on distortion. Figs. 5, 14, 20.
5 column eap	Even as possible qwerty on 5 columns. No order distortion. typability properties fixed by the choice of even-as-possible. Figs. 4C, 14.

Summary of some relevant prior art

Fig. 3/37

A



	Z	X	K	G	B	V	Q	J	
	P	W	F	U	L	C	M	Y	
D	H	I	A	T	E	N	S	O	R

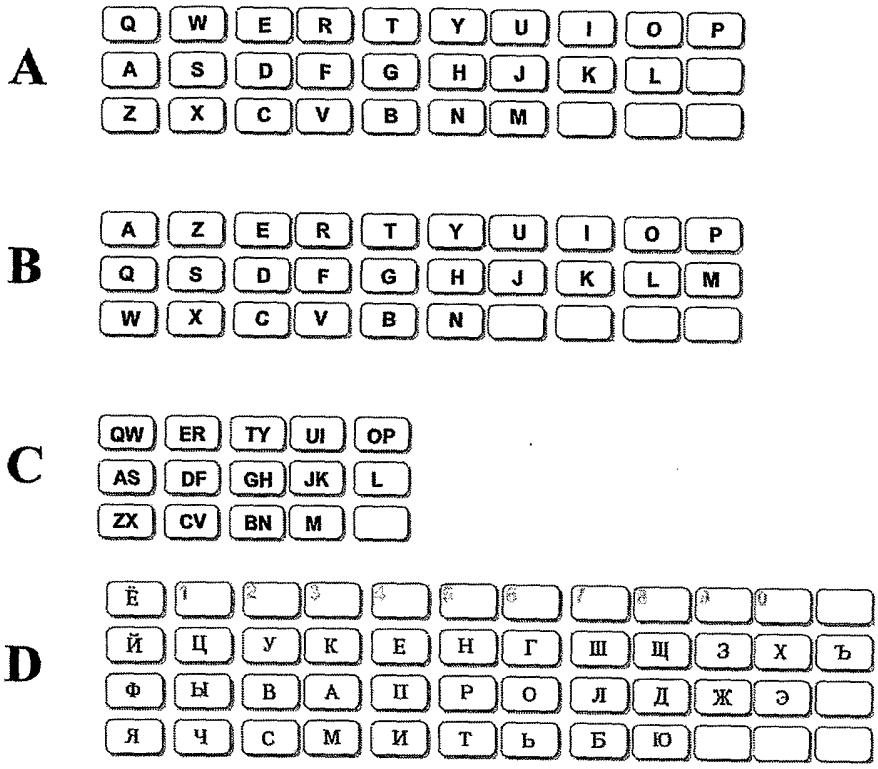
B

"	<	>	P	Y	F	G	C	R	L
A	O	E	U	I	D	H	T	N	S
:	Q	J	K	X	B	M	W	V	Z

C

PRIOR ART

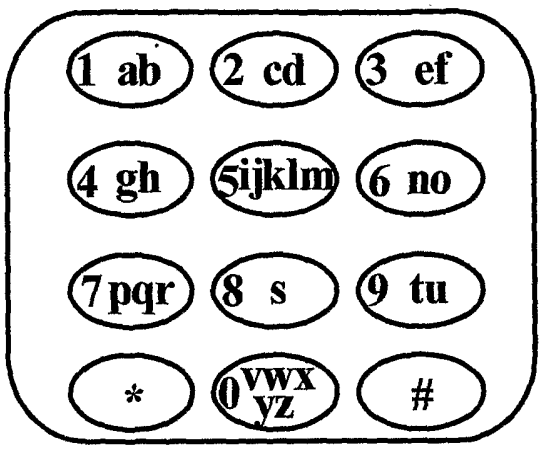
Fig. 4/37



PRIOR ART

Fig. 5/37

A



B

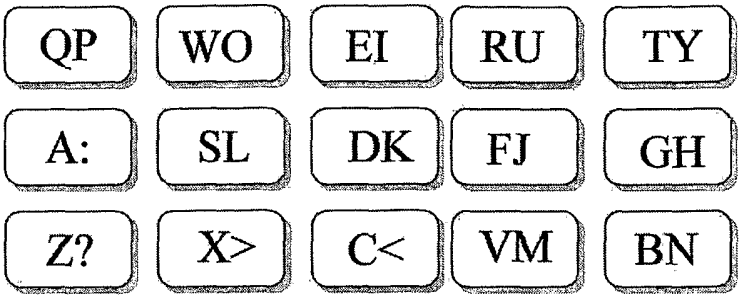
qwe	r	t	yu	i	o	p
as	d	f	space	g	hjk	l
	zxc	vb	n	m		

C

w	r	t	*b*u	*g*i	o*v*	p
a*f*	s	d	space	*e*j	k*y*	l
	*h*z	cx		n	m*q*	

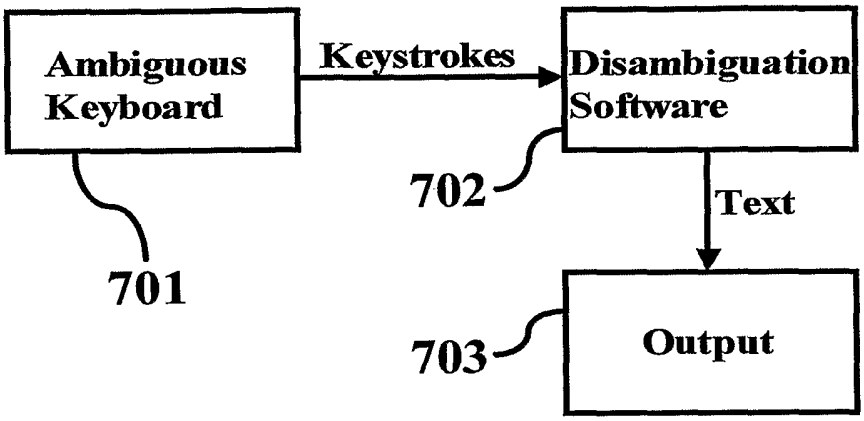
PRIOR ART

Fig. 6/37



PRIOR ART

Fig. 7/37



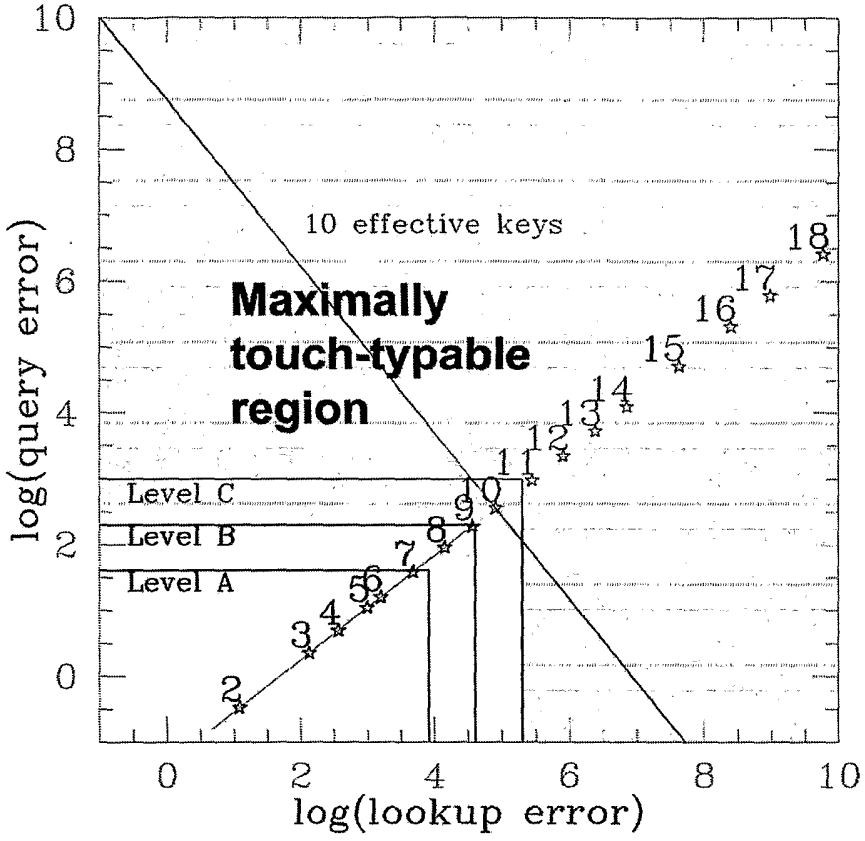
PRIOR ART

Fig. 8/37

Name	Brief Description
Lookup Error	In word-based disambiguation, the probability that the wrong word from the dictionary is presented to the user.
Query Error	In word-based disambiguation, the probability that there is more than one word from the dictionary corresponding to a given keystroke sequence.
Effective Key Number	The number of keys which would be required to achieve the given (lookup, query) if letters could be distributed over the keys arbitrarily.
Keystrokes per character	The average number of keystrokes needed to enter a character.
Drumroll Probability	The probability that two sequential letters are typed with different digits.
Effective Drumroll Probability	The drumroll probability adjusted for steric interference due to small keyboard size.
Fitts' Law	A formula relating the time to type two keys successively as a function of key size and distance between keys.
Throughput	The average number of characters per time period which can be input by the keyboard.
Robustness	Ability to contain typing errors.
Language Generality	Though optimized for one language, works well for another language or set of languages.

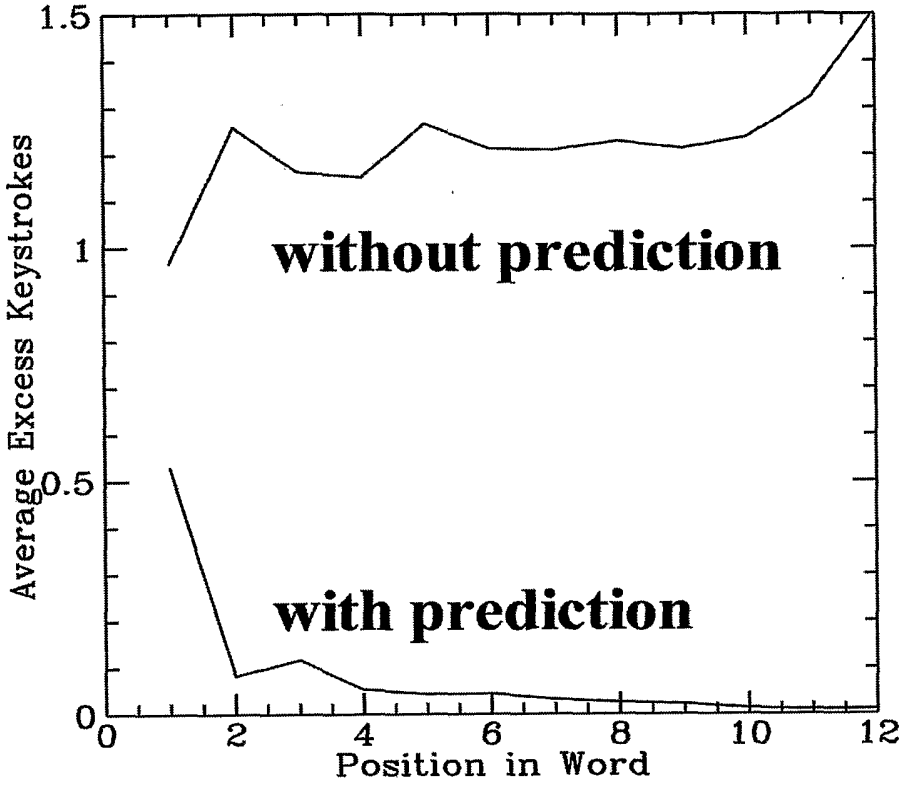
Illustrative Typability Constraints

Fig. 9/37



PRIOR ART

Fig. 10/37



PRIOR ART

Fig. 11/37

Name	Brief Description
Even-as-possible	Letters are distributed over keys such that each key has the same number of letters; as nearly as that is possible, given the number of keys, and the number of letters.
Max (min) num letters per key	No key has more than (less than) the given number of letters assigned to it.
Range	The difference between the greatest number of letters on a key and the least number of letters/key.
Dominant class size	The size of the largest subset of keys with a given number of letters assigned.
Left-right symmetry	Properties related to the balance of left and right halves of the keyboard, such as the property that the number of letters on a key in a given column on the left side is as close as possible to the same as the number of letters on a key in the symmetric column on the right side.
Up-down symmetry	Properties related to the balance of top and bottom halves of the keyboard.
Monotonicity	Properties related to systematic spatial variation.

Illustrative Appearance Distortion Constraints

(Partition related)

Fig. 12/37

Name	Brief Description
Reading order	Distortions early in the reading order cost more than distortions later in the order
Row (column)-limited reading order	Distortions at the beginning of each row (column) cost more than distortions later in the row (column)
Keyboard name	Distortion to letters in the keyboard name cost more than distortions which do not affect the name
Exterior	Distortions in the extreme left , right , top, bottom or some subset cost more than distortions in the interior
Row (column) limited	Letters can only be moved in the same row (column)
Distance limited	Letters can only be moved a certain distance away from their original position
Number	The number of letters displaced from their original position
Number of exchanges	The number of pairs of letters which whose position is exchanged relative to the original keyboard

Illustrative Appearance Distortion Constraints

(Order related)

Fig. 13/37

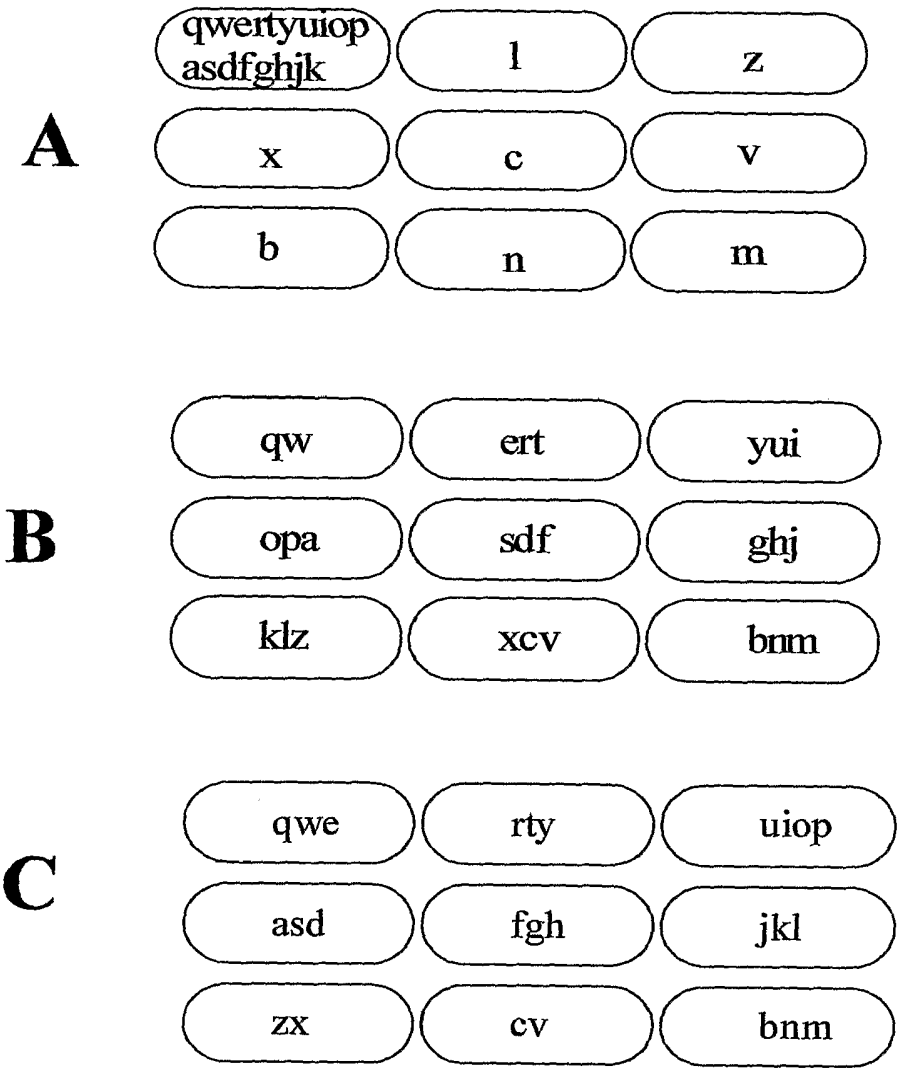
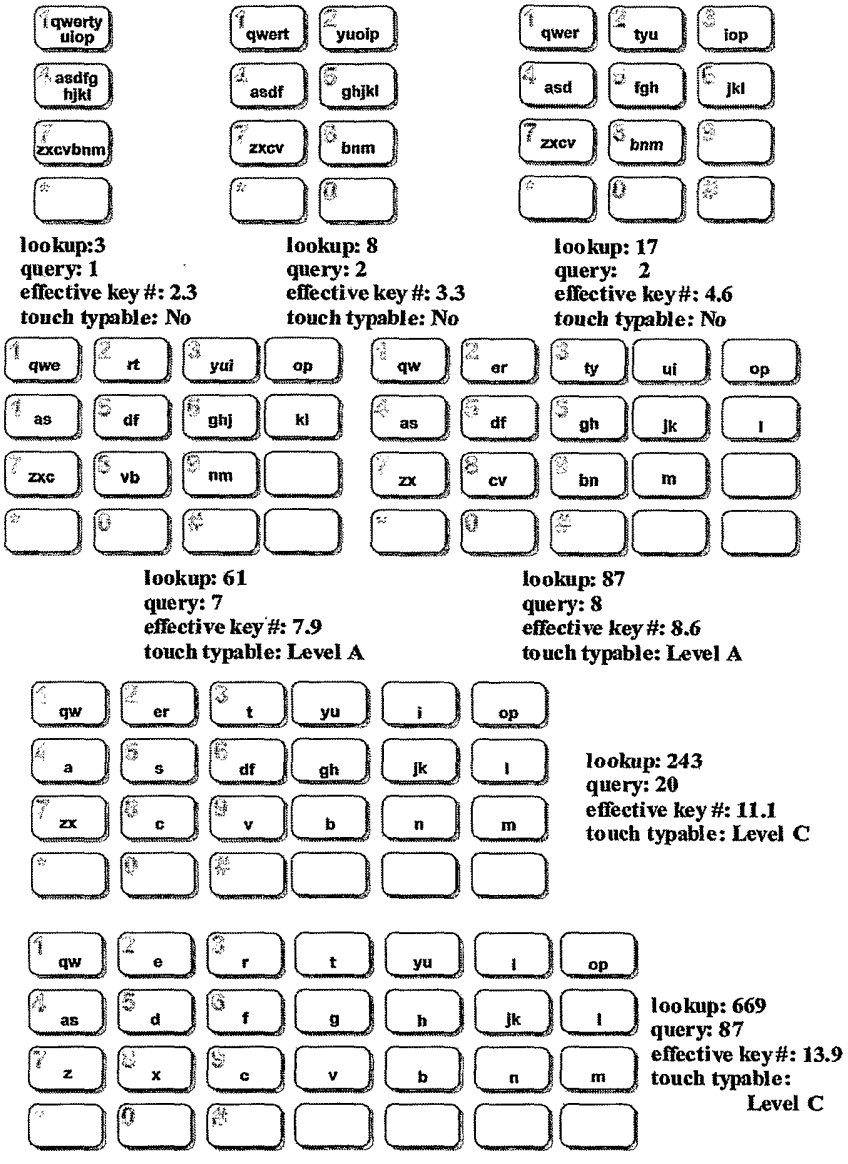

A
qwertyuiop asdfghjk
l
z
x
c
v
b
n
m
B
qw
ert
yui
opa
sdf
ghj
klz
xcv
bnm
C
qwe
rty
uiop
asd
fgh
jkl
zx
cv
bnm

Fig. 14/37



PRIOR ART

Fig. 15/37

Name	Brief Description
Same digit	Letter is typed with the same digit (finger or thumb) in the distorted and original keyboard
Symmetric digit	Letter is typed with a symmetric digit , e.g. index finger of the left hand in the original and index finger of the right hand in the distorted keyboard
Same hand	Letter is typed with the same hand in both original and distorted keyboard (but perhaps a different digit)
Nearby digit	Letter is typed in the distorted keyboard with a digit which is nearby the digit used in the original keyboard
Same gesture class	Letter is in the same gesture class in the original and distorted keyboard, e.g. the class of gestures which include moving one row and one column from the home row to obtain the target letter

Illustrative Gesture

Distortion Constraints

Fig. 16/37

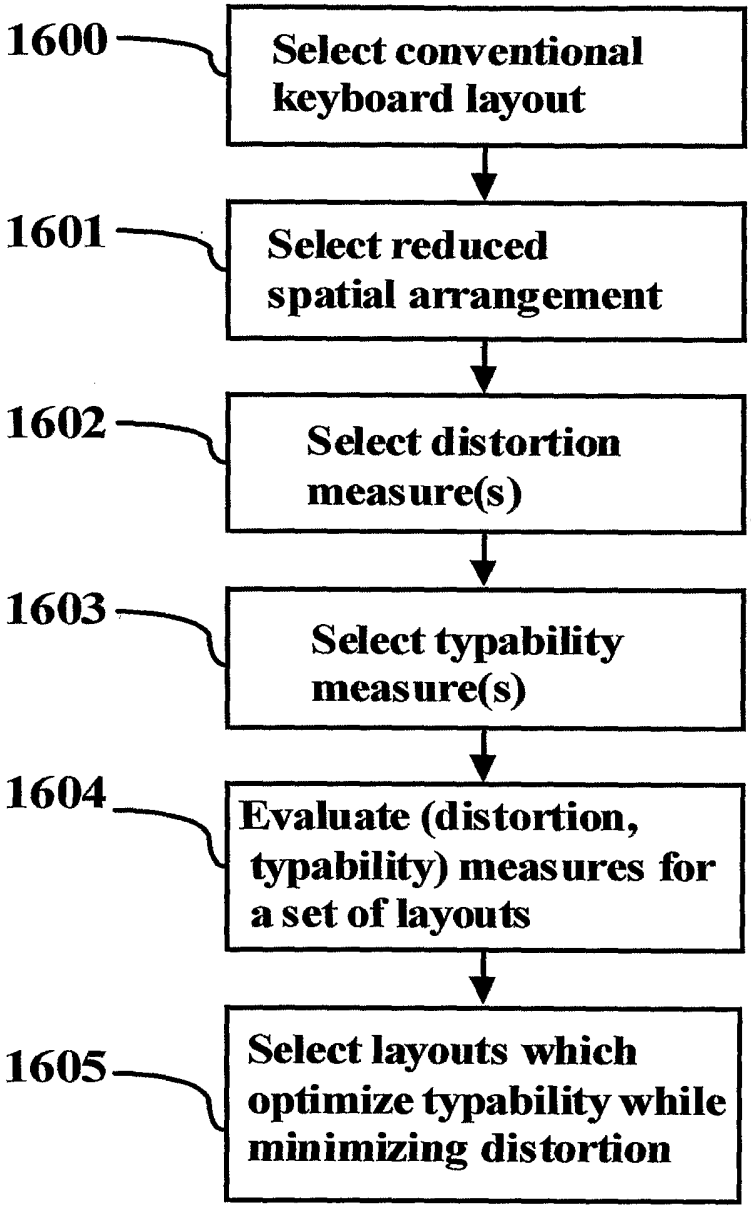

1600
Select conventional keyboard layout
1601
Select reduced spatial arrangement
1602
Select distortion measure(s)
1603
Select typability measure(s)
1604
Evaluate (distortion, typability) measures for a set of layouts
1605
Select layouts which optimize typability while minimizing distortion

Fig. 17/37

Name	Brief Description
Qwerty-glu	Qwerty-confined to a telephone keypad, with limits on distortion, learnability, and typability
5-column	More severe limits than Qwerty-glu, but also more keys
Alpha 2-key	Conserves alphabetic order
Qwerty 2-key	Conserves qwerty order, and 2-thumb interaction method for Qwerty
Consonant-Vowel 2-key	Uses a symbolic method only, without reference to conventional layout
Steering Wheel	Finger gesture conservation
Steric Hindrance	Compensate for relative size of digits and keypad by providing an additional Next key
Multiple Interaction	Keyboard simultaneously optimized for two distinct interaction mechanism

Summary of embodiments illustrating typability and distortion tradeoffs

Fig. 18/37

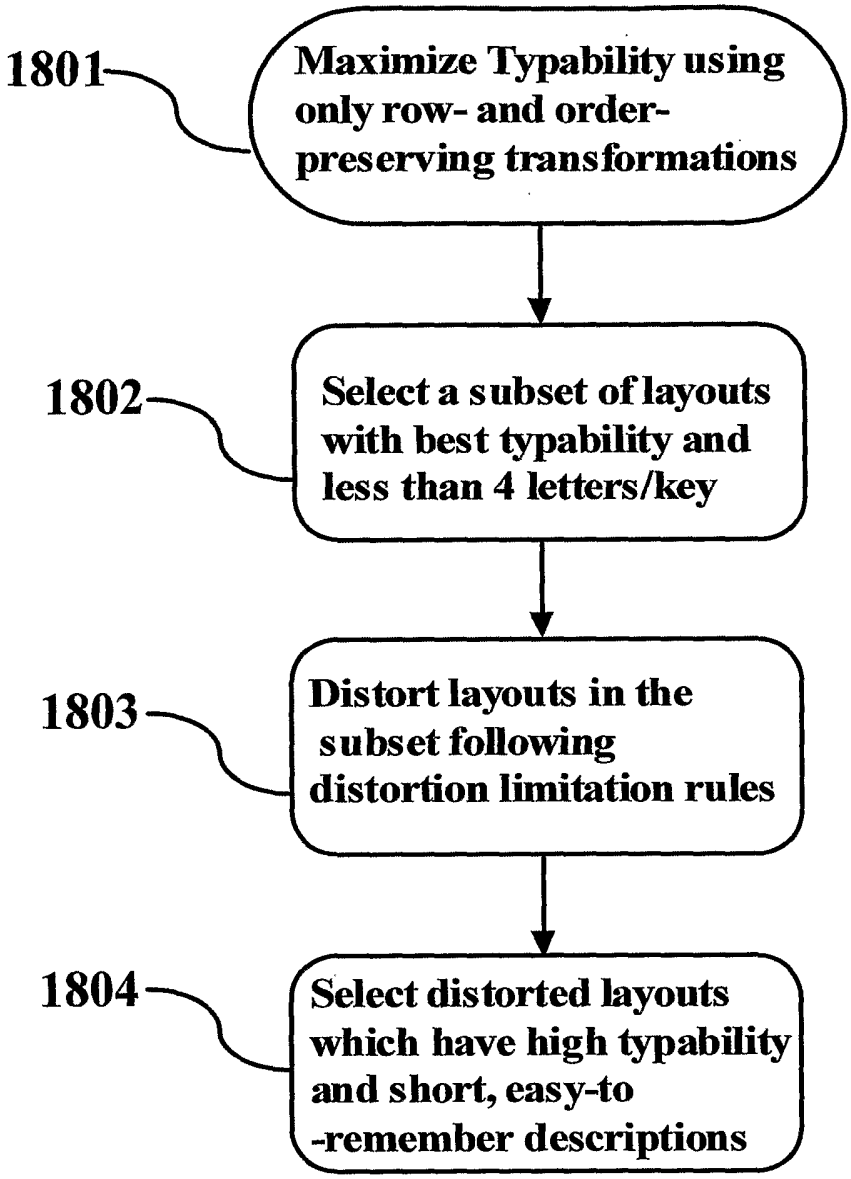

1801
Maximize Typability using only row- and order-preserving transformations
1802
Select a subset of layouts with best typability and less than 4 letters/key
1803
Distort layouts in the subset following distortion limitation rules
1804
Select distorted layouts which have high typability and short, easy-to-remember descriptions

Fig. 19/37

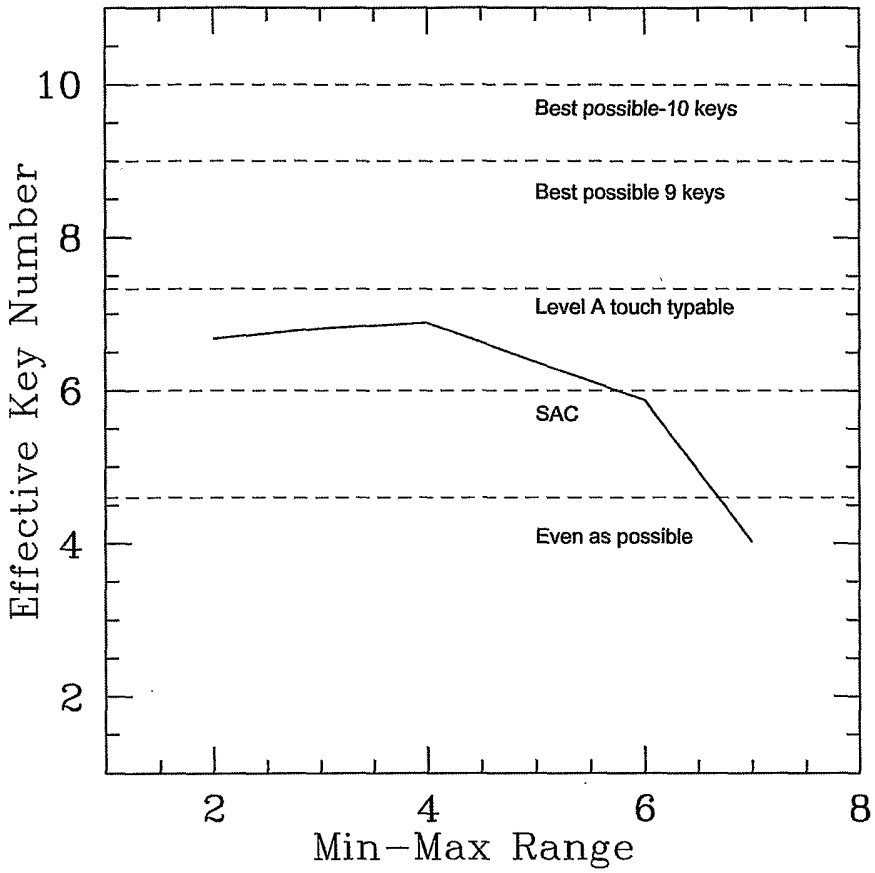

Effective Key Number
10
8
6
4
2
Best possible-10 keys
Best possible 9 keys
Level A touch typable
SAC
Even as possible
2
4
6
8
Min-Max Range

Fig. 20/37

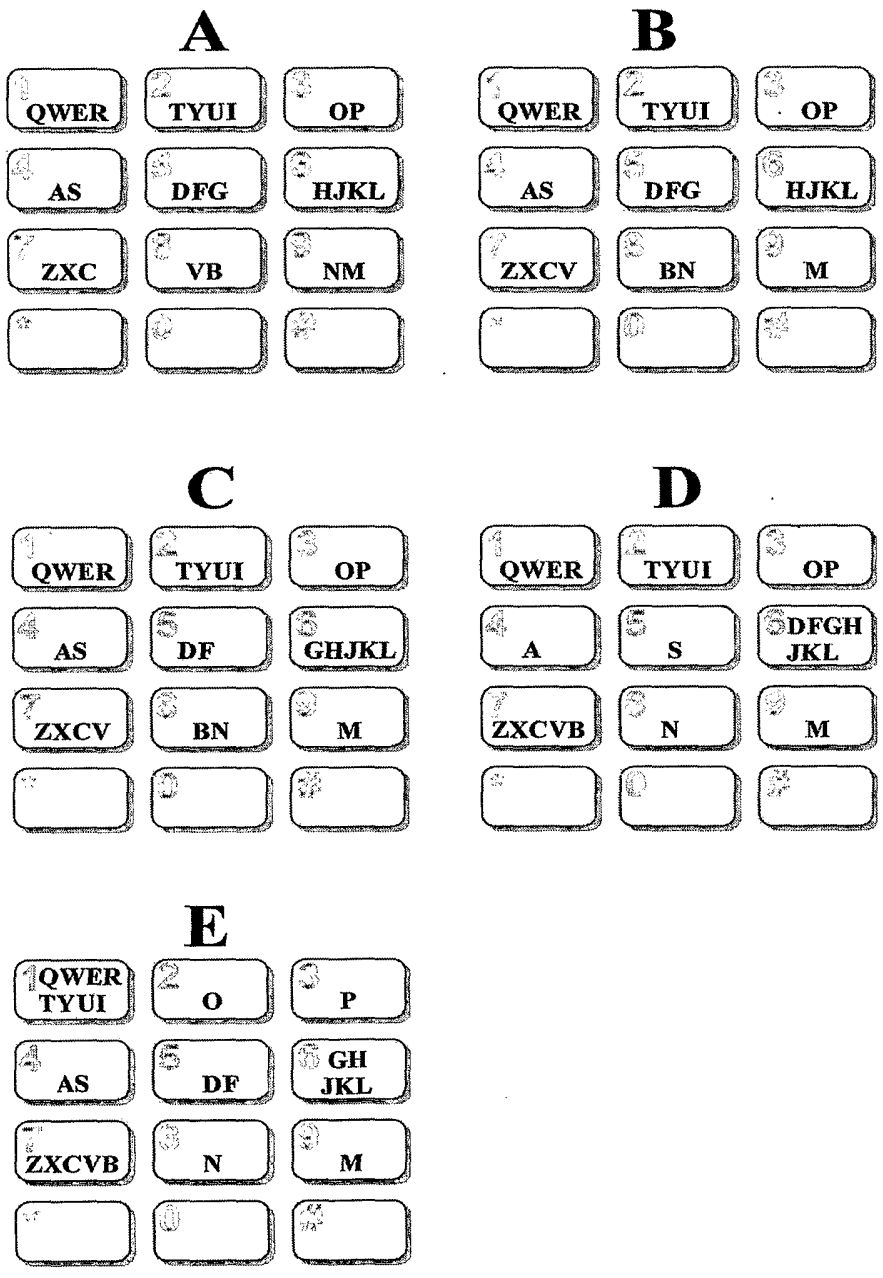

A
1 QWER
2 TYUI
3 OP
4 AS
5 DFG
6 HJKL
7 ZXC
8 VB
9 NM
B
1 QWER
2 TYUI
3 OP
4 AS
5 DFG
6 HJKL
7 ZXCV
8 BN
9 M
C
1 QWER
2 TYUI
3 OP
4 AS
5 DF
6 GHJKL
7 ZXCV
8 BN
9 M
D
1 QWER
2 TYUI
3 OP
4 A
5 S
6 DFGH JKL
7 ZXCVB
8 N
9 M
E
1 QWER TYUI
2 O
3 P
4 AS
5 DF
6 GH JKL
7 ZXCVB
8 N
9 M

Fig. 21/37

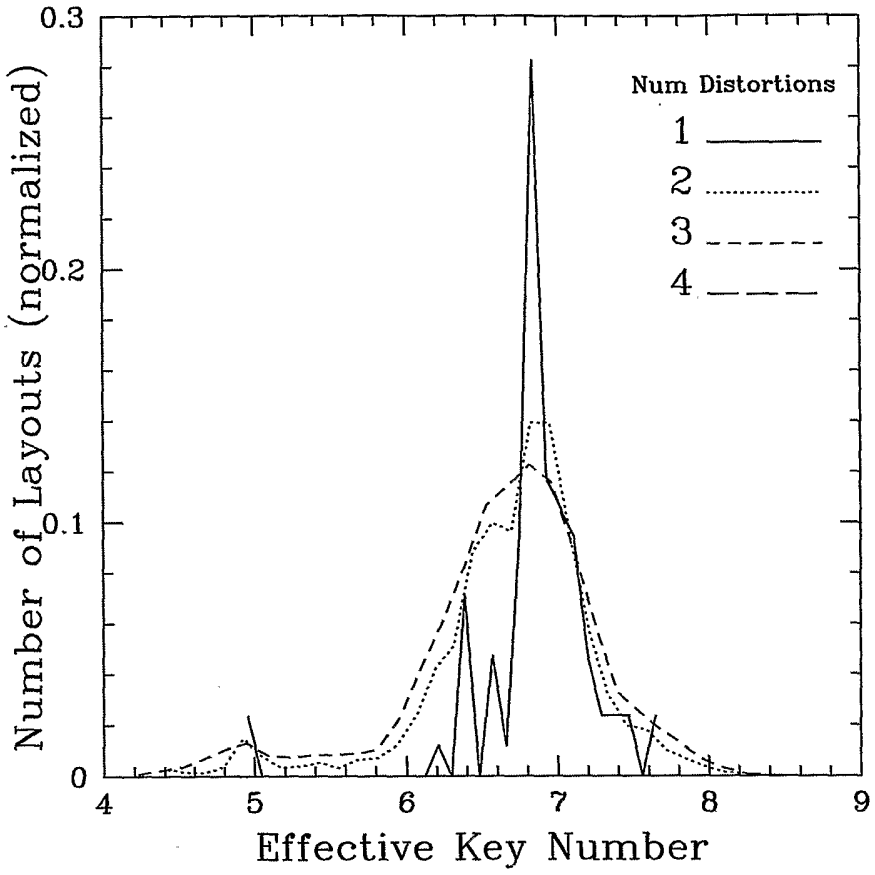

0.3
0.2
0.1
0
Number of Layouts (normalized)
4
5
6
7
8
9
Effective Key Number
Num Distortions
1
2
3
4

Fig. 22/37

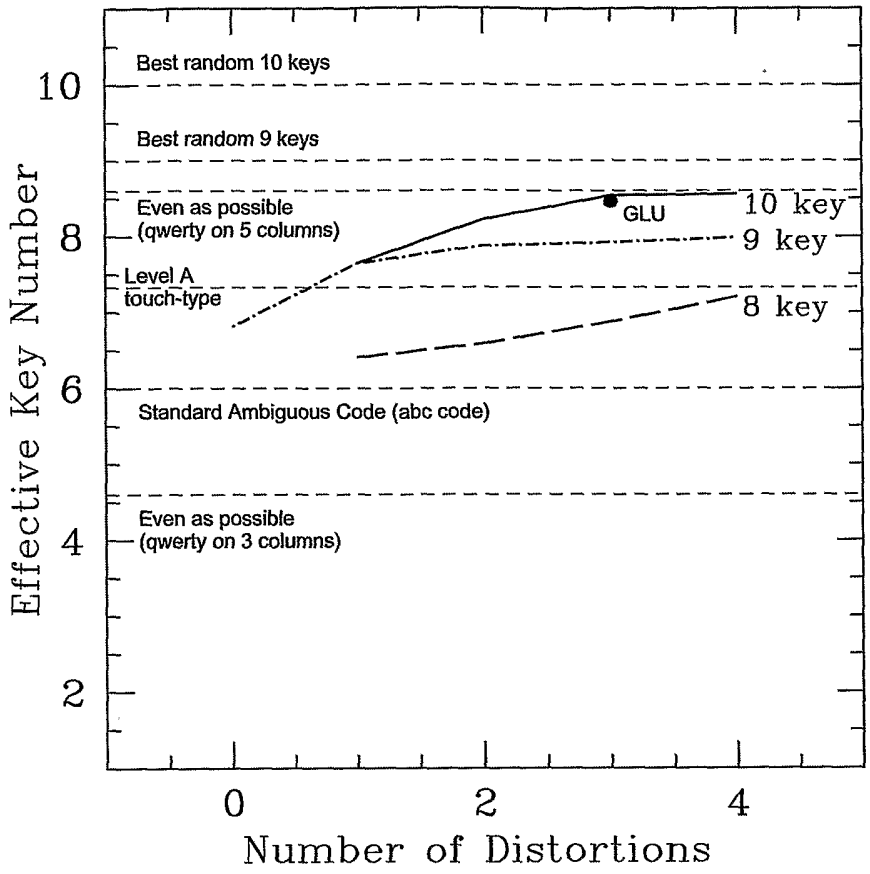

Best random 10 keys
Best random 9 keys
Even as possible
(qwerty on 5 columns)
Level A
touch-type
GLU
10 key
9 key
8 key
Standard Ambiguous Code (abc code)
Even as possible
(qwerty on 3 columns)
Effective Key Number
10
8
6
4
2
0
2
4
Number of Distortions

Fig. 23/37

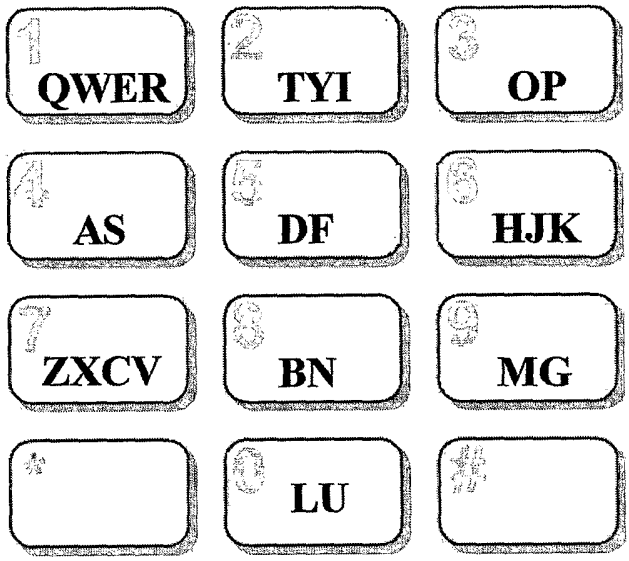


Fig. 24/37

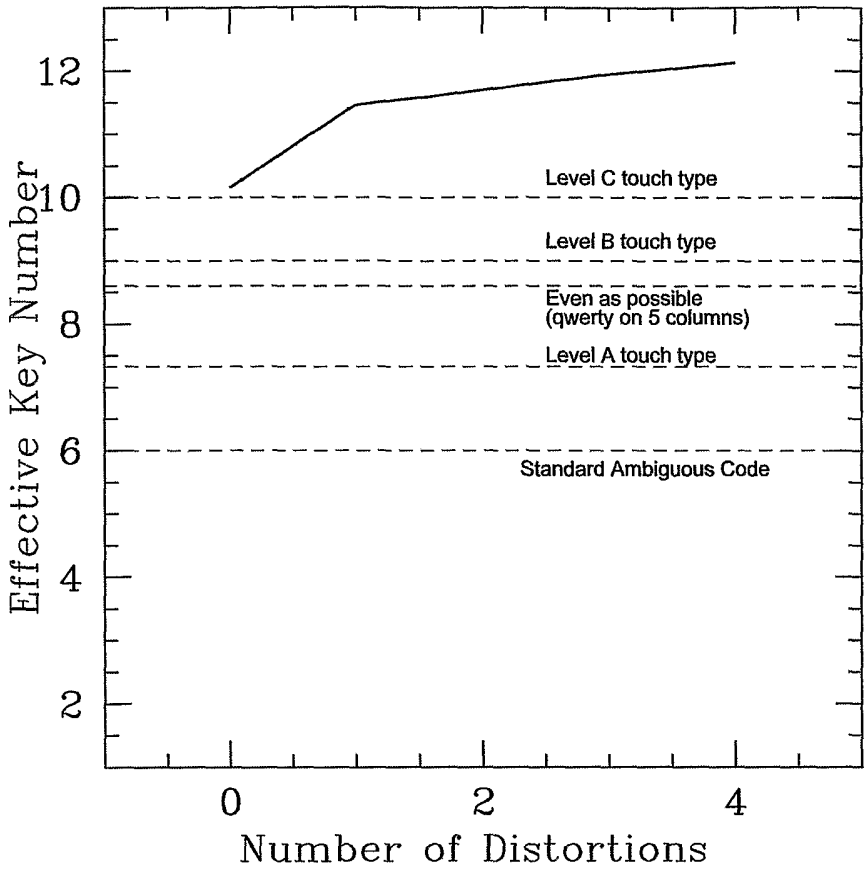
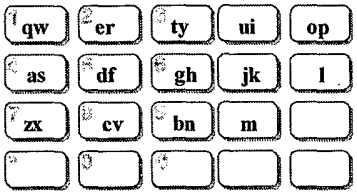
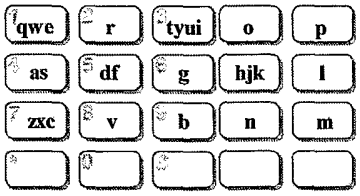

Effective Key Number
12
10
8
6
4
2
0
2
4
Number of Distortions
Level C touch type
Level B touch type
Even as possible
(qwerty on 5 columns)
Level A touch type
Standard Ambiguous Code

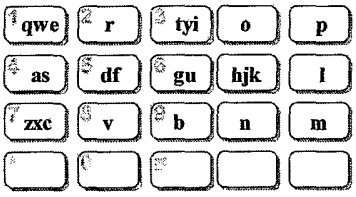
Fig. 25/37



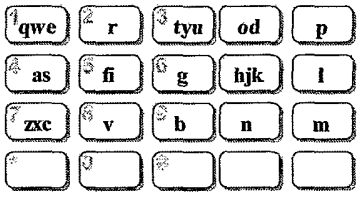
A



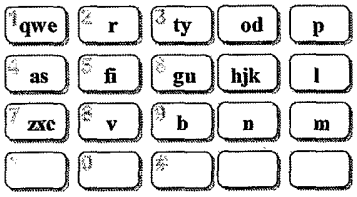
B



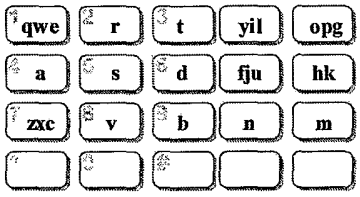
C



D



D



E

Fig. 26/37

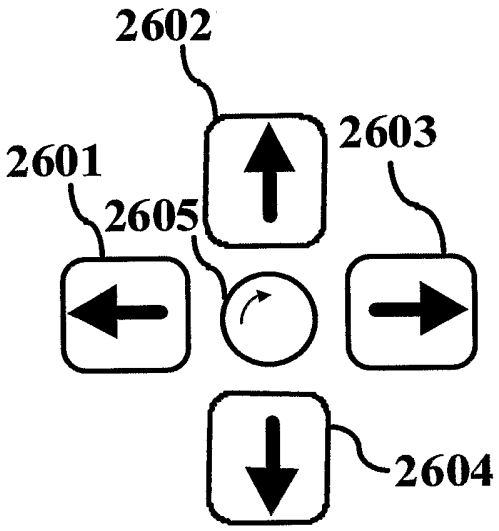


Fig. 27/37

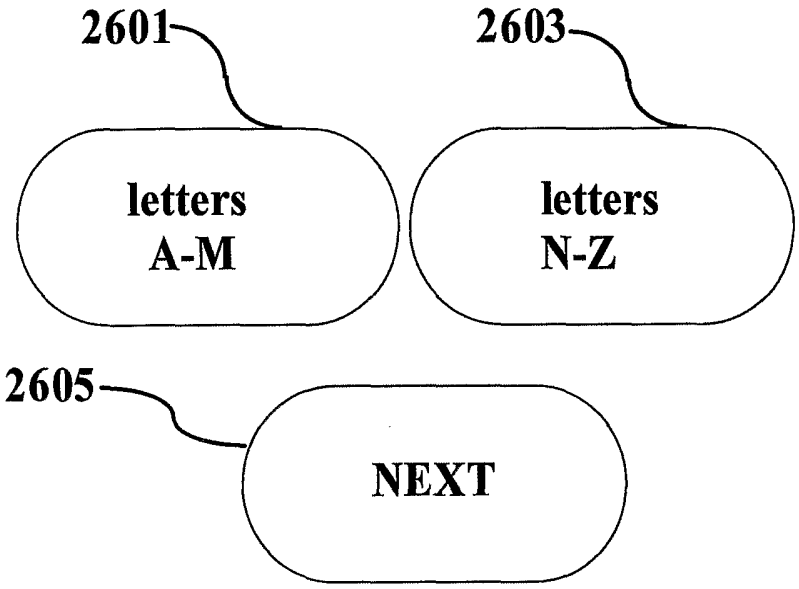


Fig. 28/37

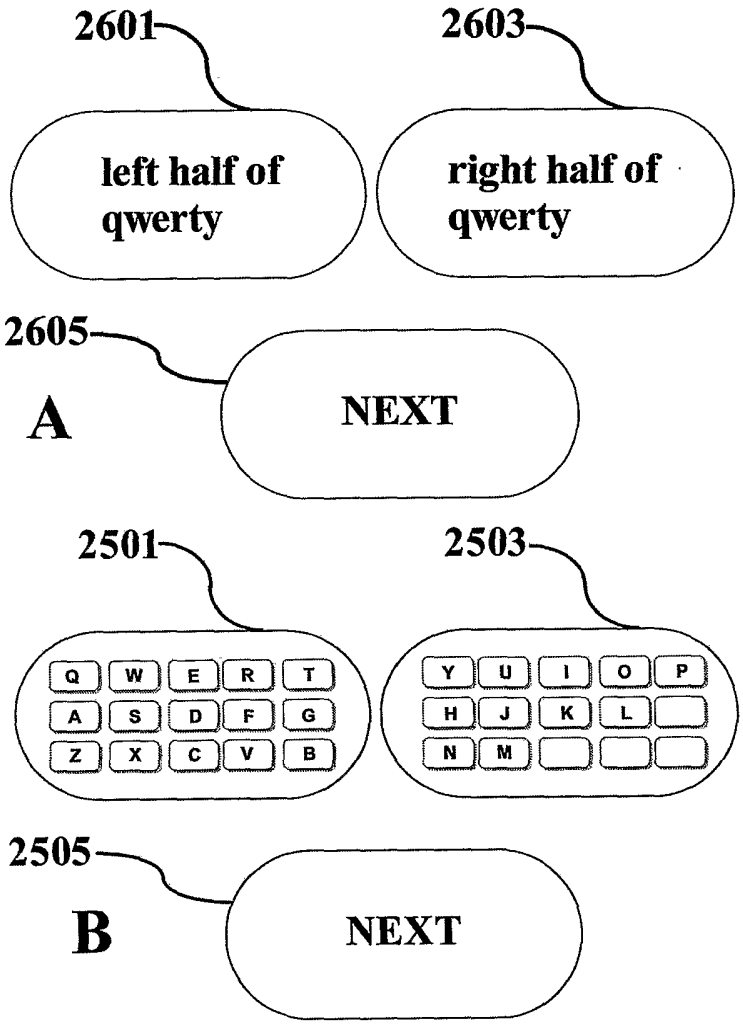

2601
2603
left half of qwerty
right half of qwerty
2605
A
NEXT
2501
2503
Q W E R T
A S D F G
Z X C V B
Y U I O P
H J K L
N M
2505
B
NEXT

Fig. 29/37

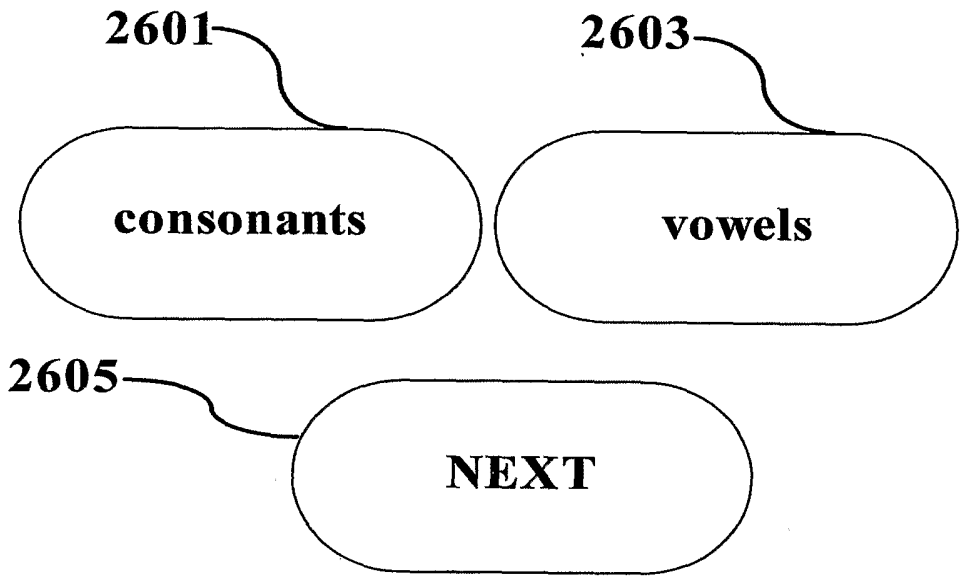


Fig. 30/37

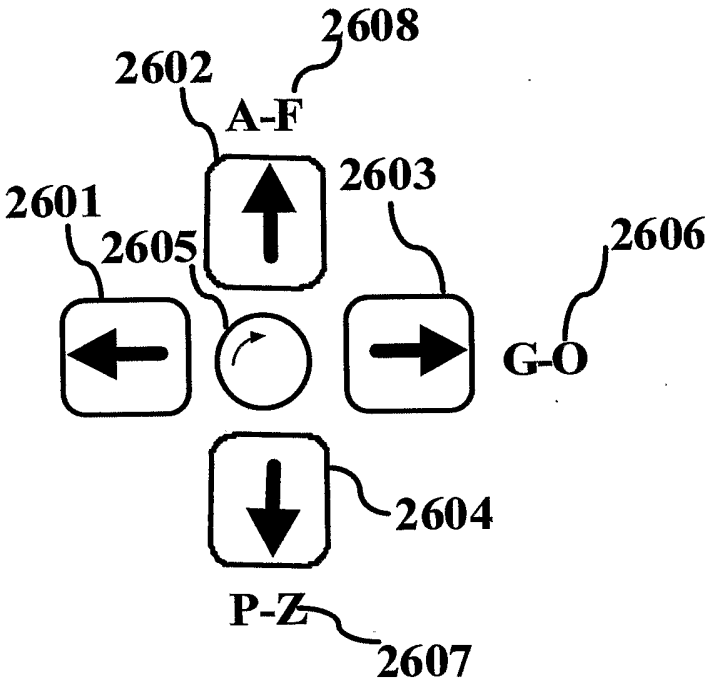
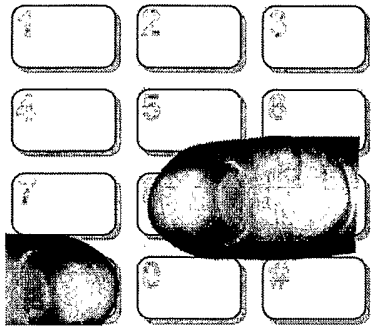
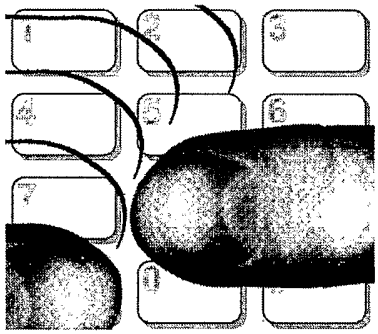


Fig. 31/37

A



B



C

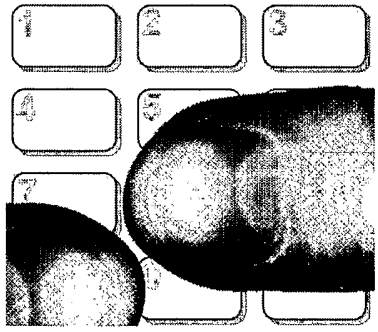


Fig. 32/37

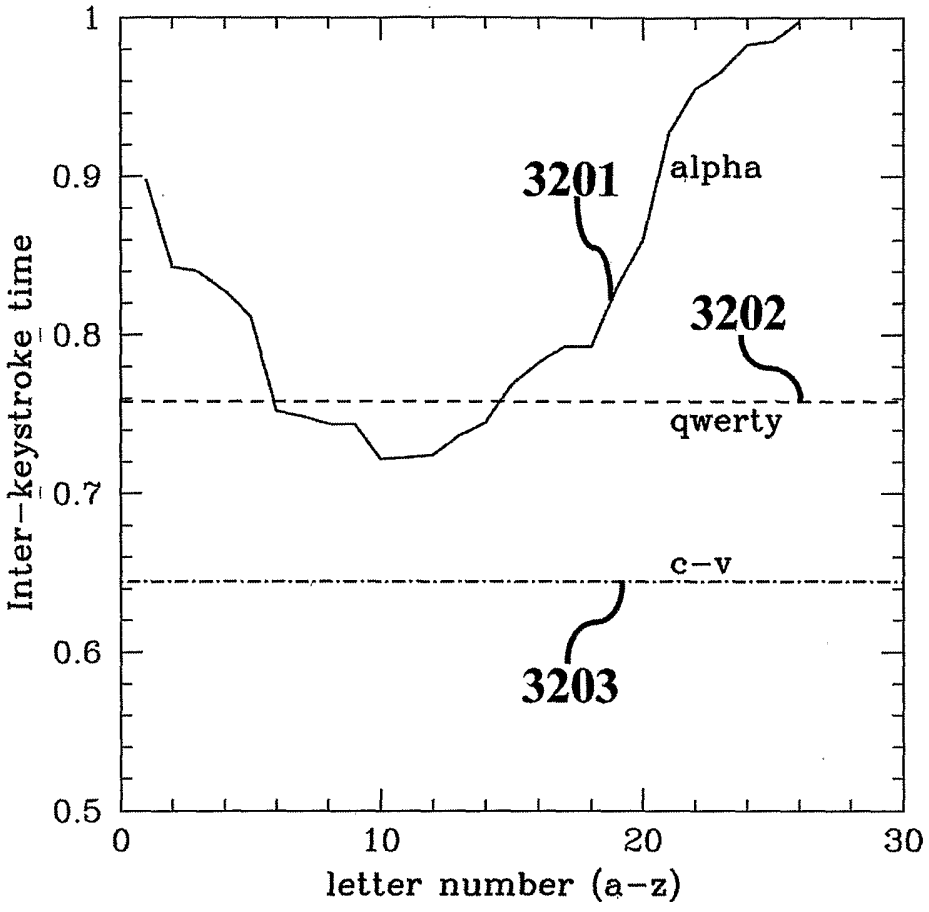

1
0.9
0.8
0.7
0.6
0.5
Inter-keystroke time
0
10
20
30
letter number (a-z)
3201
alpha
3202
qwerty
c-v
3203

Fig. 33/37

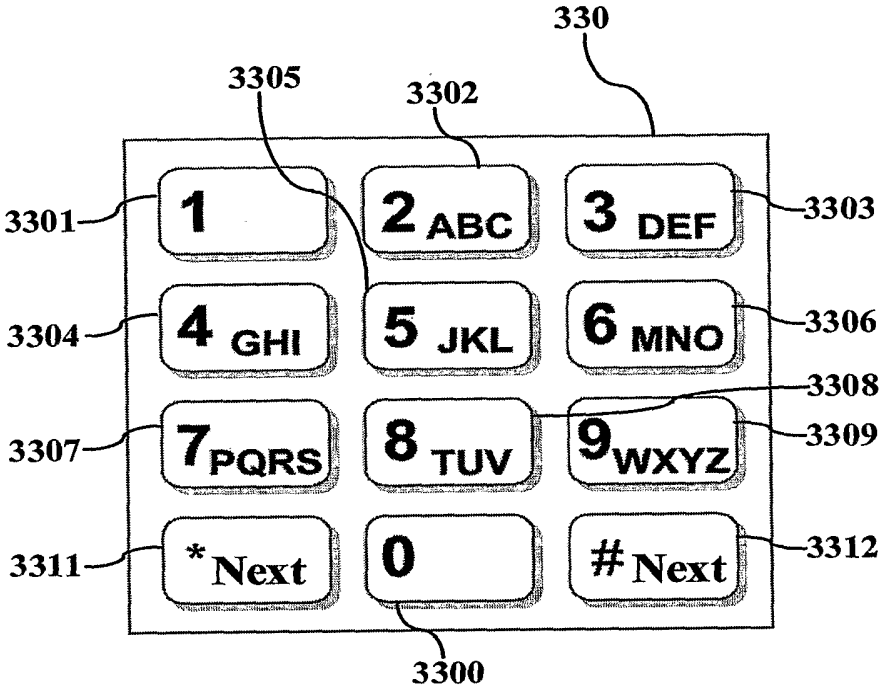

330
3305
3302
3301
1
2 ABC
3 DEF
3303
3304
4 GHI
5 JKL
6 MNO
3306
3308
3307
7 PQRS
8 TUV
9 WXYZ
3309
3311
*Next
0
#Next
3312
3300

Fig. 34/37

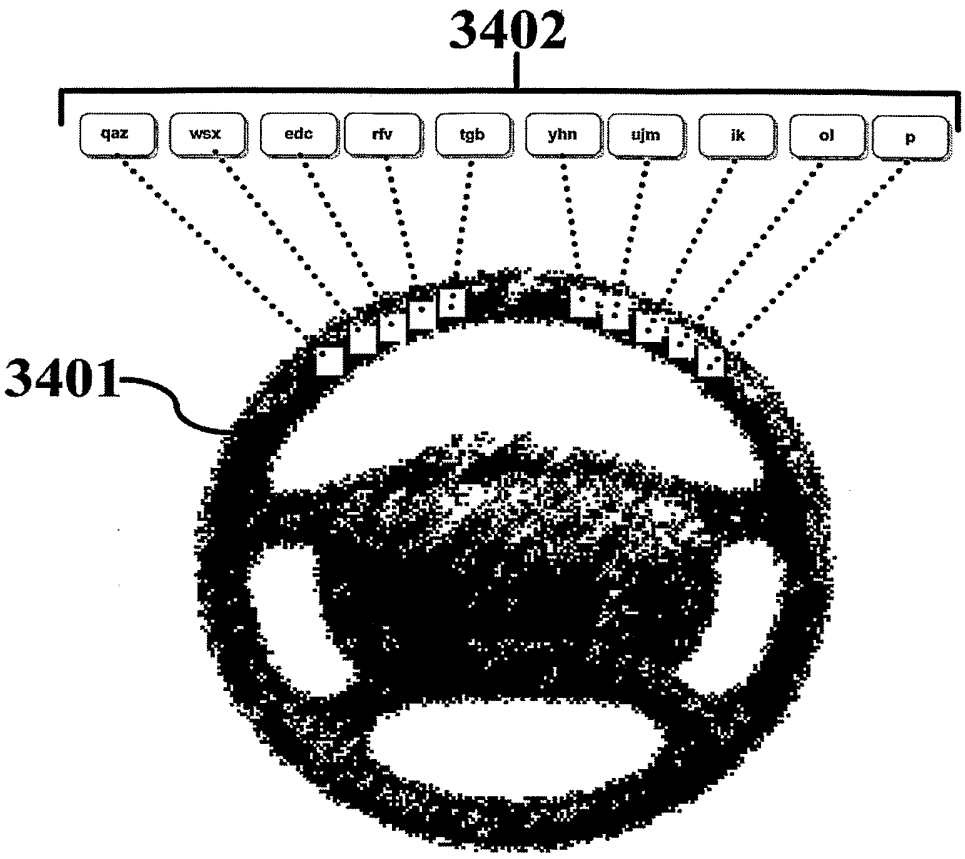


Fig. 35/37

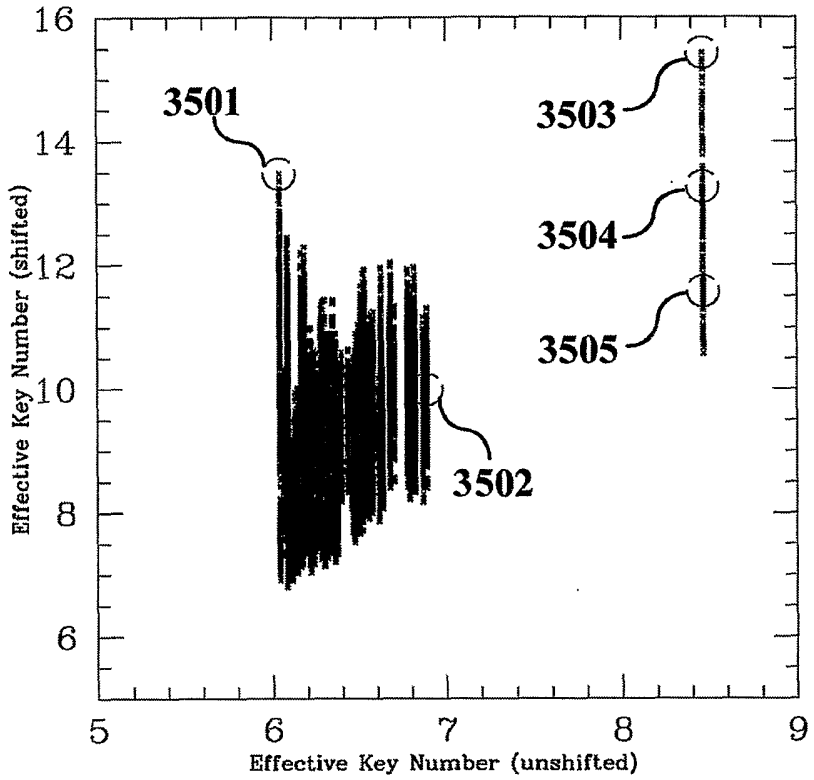

16
14
12
10
8
6
5
6
7
8
9
Effective Key Number (shifted)
Effective Key Number (unshifted)
3501
3502
3503
3504
3505

Fig. 36/37

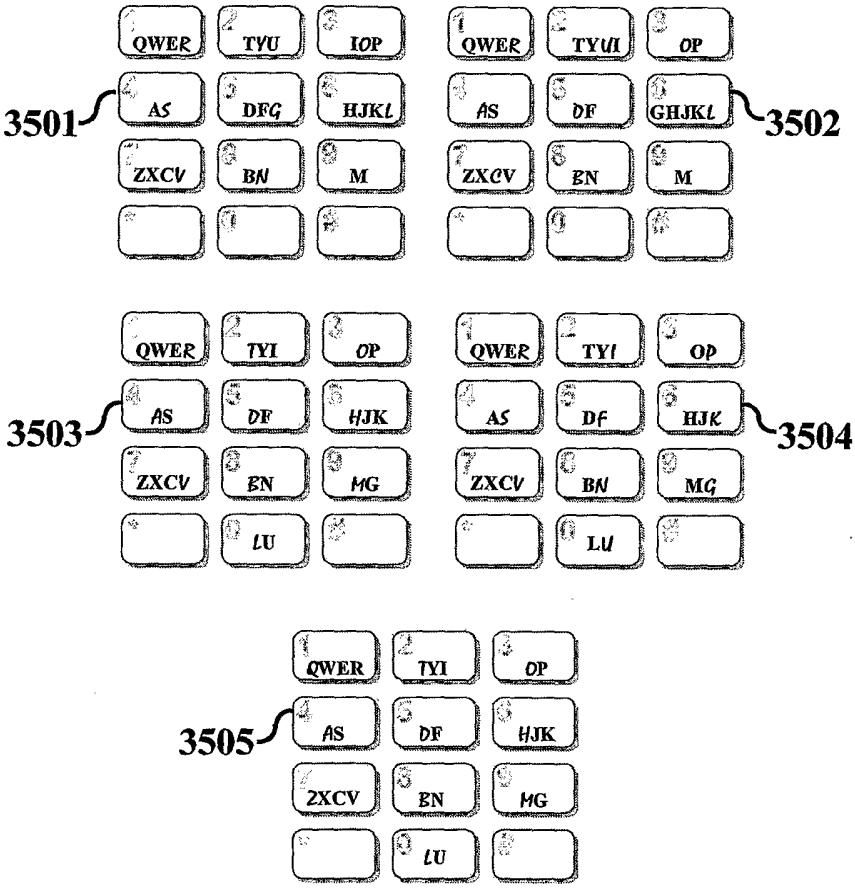
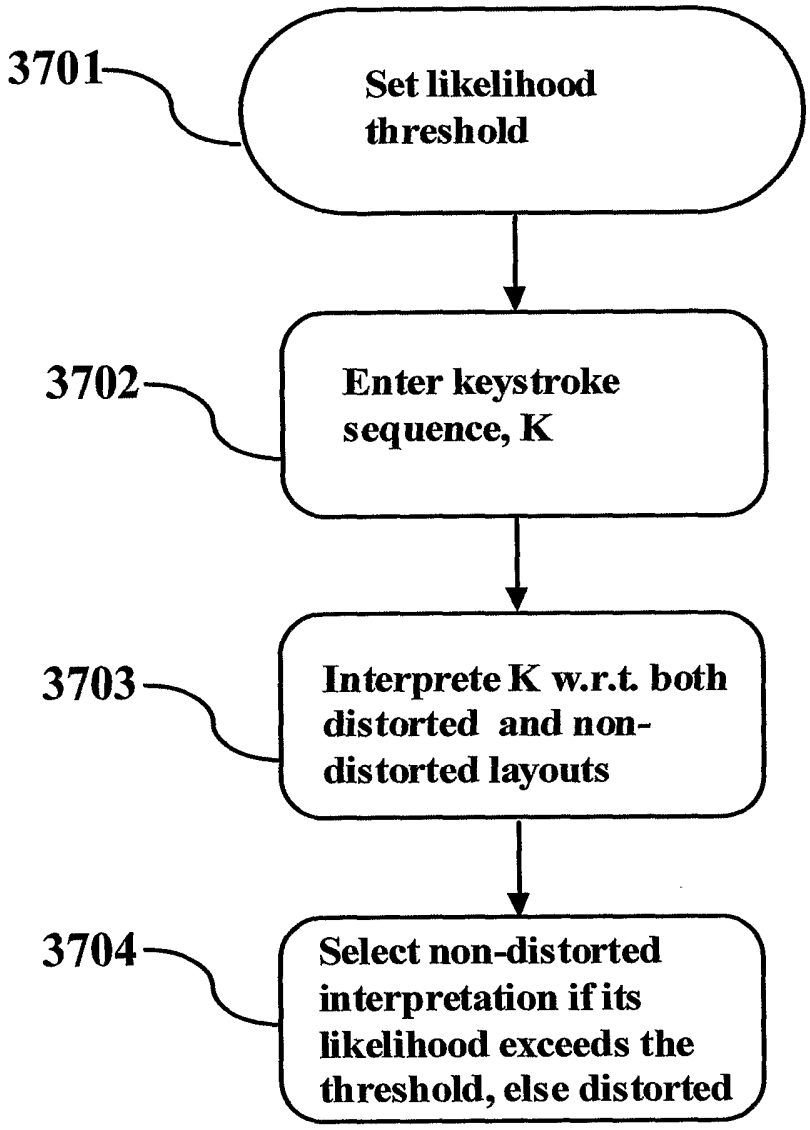

3501
QWER
TYU
IOP
AS
DFG
HJKL
ZXCV
BN
M
3502
QWER
TYUI
OP
AS
DF
GHJKL
ZXCV
BN
M
3503
QWER
TYI
OP
AS
DF
HJK
ZXCV
BN
MG
LU
3504
QWER
TYI
OP
AS
DF
HJK
ZXCV
BN
MG
LU
3505
QWER
TYI
OP
AS
DF
HJK
ZXCV
BN
MG
LU

Fig. 37/37


3701
Set likelihood threshold
3702
Enter keystroke sequence, K
3703
Interprete K w.r.t. both distorted and non-distorted layouts
3704
Select non-distorted interpretation if its likelihood exceeds the threshold, else distorted

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US05/03093

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H03M 11/00; H03M 13/00.
US CL : 341/22,23,26,28,67;345/168;715/811,816,783,847,810.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 341/22,23,26,28,67;345/168;715/811,816,783,847,810.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST:keyboard, keypad, ambiguous, distortion, vowels,consonants,letters,symbols.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,734,881 B1 (WILL) 11 May 2004 (11.05.2004), figures 4 and 5.	1-7, 9, 10 and 13-25
---		---
Y		11-12
Y	US 6,703,963 B2 (HIGGINSON) 09 March 2004 (09.03.2004), figure 5a.	11-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
25 August 2005 (25.08.2005)

Date of mailing of the international search report
27 OCT 2005

Name and mailing address of the ISA/US
Mail Stop PCT, Attn: ISA/US
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
Facsimile No. (703) 305-3230

Authorized officer
Michael Horabik
Telephone No. 571-272-3069

Form PCT/ISA/210 (second sheet) (January 2004)