# A Practical Pressure Sensitive Computer Keyboard

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## ABSTRACT

A pressure sensitive computer keyboard is presented that independently senses the force level on every depressed key. The design leverages existing membrane technologies and is suitable for low-cost, high-volume manufacturing. A number of representative applications are discussed.

**ACM Classification:** H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

**General terms:** Design, Human Factors.

**Keywords:** Force Pressure Sensitive Keyboard

## INTRODUCTION

While a great many advances have been made in the field of human-computer interaction, it is sobering to note that most computer input still happens at keyboards that have changed very little since the dawn of the computer age. This is surprising since there are numerous examples of systems that are clearly superior. For example, court stenographers must demonstrate at least 95% accuracy when recording two-voice testimony at 225 words per minute [1]. This would be an astounding rate for a typist at a QWERTY keyboard.

Unfortunately, the amazing performance of stenographers comes only after a major investment in training. This presents a significant barrier to mass adoption. In fact, many desirable optimizations become impractical when retraining costs are considered. Most successful computer keyboards make only minor changes to the standard layout and mode of operation.

The evolution of electronic keyboard instruments for music performance provides clues to improving computer keyboards while leveraging existing skills. Music keyboards mimic the design of piano keyboards, including features such as velocity sensitivity and weighted keys. High-end keyboards go beyond this, adding features such as pressure sensing (“aftertouch”) and multi-level position sensing (“displacement sensitivity”) which can be used to control a wide variety of synthesizer parameters in real-time. By analogy, one might expect that adding these sorts of sensing capabilities to computer keyboards would be similarly successful. There has been a significant amount of work along these lines that supports this conclusion (discussed in the next section). Understandably, these earlier efforts did not address issues of cost or manufacturability.

In this paper, we introduce a practical pressure sensitive keyboard. This device looks and feels exactly like an ordinary keyboard. However, it can report the pressure on every depressed key independently. We will explain how this keyboard can be mass produced using existing keyboard manufacturing technology for a very modest increase in cost. In the final section, we will explore some of the compelling interactions that become possible with such a device.

## PRIOR WORK

There is a considerable body of work on the use of pressure sensitivity in interactive systems. Buxton [2] provides an excellent overview of touch computing systems, and notes that pressure sensitive devices for electronic music pre-date the personal computer. More recent work has examined the use of pressure sensitivity to augment GUI objects. [3, 4, 5]. A key finding of Ramos, et al, was that users were generally able to generate 6 discernable pressure levels in selection tasks, when adequate visual feedback is provided [3].

DiMicco briefly describes the use of a keyboard augmented with pressure sensors (apparently measuring overall pressure level on the keyboard) to detect emotions [6].

FASTY was a program to examine methods to improve text generation for disabled people that included the use of pressure sensitive keyboards [7]. The hardware apparently was intended to use Force Sensing Resistors under each key. However, it is unclear if this plan was ever fully implemented.

Loy et al describe the use of a pressure sensitive keyboard for biometric user authentication [8]. Their keyboard used sensors based on pressure sensitive ink placed under each key. This is one of the most capable systems reported in the literature, however, it makes use of a considerable amount of expensive laboratory instrumentation, and was never intended for, and is not suitable for, mass production.


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## KEYBOARD CONSTRUCTION

While computer keyboards may not have changed much externally, their internal construction has evolved considerably. The early days of personal computers saw numerous designs, typically leveraging the existing printed circuit board (PCB) technology. It was not unusual for keyboards to use discrete switches soldered to a PCB. The popular IBM Model F keyboard, introduced with the IBM PC, sensed the change in capacitance as a buckling spring mechanism approached plates on a PCB [9]. These large printed circuit boards were relatively expensive.

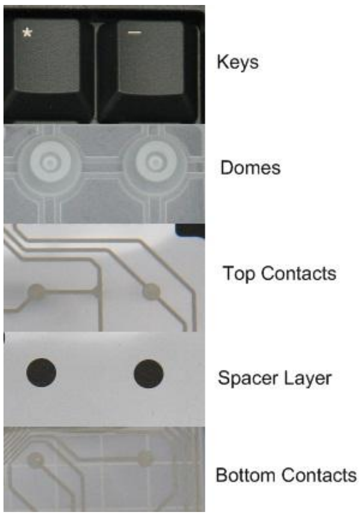


Figure 1: Flexible membrane/rubber dome keyboard construction. Keys press on rubber domes that provide the appropriate tactile sensation. In turn, the domes press on a stack of three membranes. When a key is pressed, the top sheet deforms through a hole in the spacer layer, making contact with the bottom sheet.

Most modern computer keyboards use flexible membrane technology. (A disassembled keyboard is shown in Figure 1.) A stack of three plastic sheets forms the switches. The top and bottom sheets are screen printed with conductive ink (typically silver-based) which routes row and column wires to each switch point. The middle sheet serves as a spacer. It is unprinted, and has holes at the switch points. When pressure is applied at a switch point, the top sheet deforms into the hole, making electrical contact from the top sheet conductor to the bottom sheet conductor.

Ideally, a key should give some tactile feedback to indicate when it is successfully depressed. This is typically accomplished by adding a mechanism that provides a significant nonlinearity in the force vs. distance response of the key – i.e. to give it a "click" feel. The buckling spring mechanism patented by IBM [10] was extremely popular in the early days of PCs. However, its distinctive "click-clack" noise was rather loud, and the need for a mechanism at each key made it costly. Instead, most manufacturers have adopted the quieter "rubber dome" technology. In this case, a single, molded, elastomeric sheet contains a dome structure at each key site. The dome is designed to provide the appropriate nonlinear force characteristic (by buckling the dome), and also to press on the flexible membrane layers underneath.

The combination of screen-printed, flexible membranes with elastomeric domes is what has made inexpensive, mass-produced computer keyboards possible. Given that the world is geared up to manufacturer millions of keyboards of this style every year, it would be best if any advancements in keyboards were compatible with current manufacturing processes.

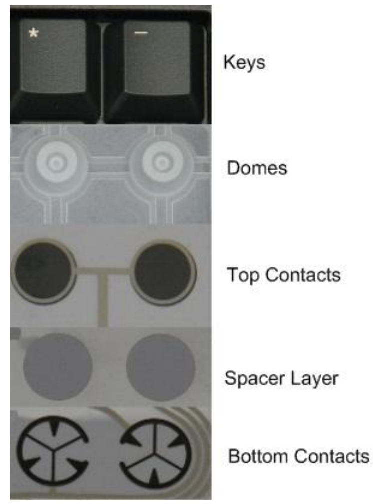


Figure 2: Pressure sensitive keyboard design. When a key is pressed, the top contact deforms through the spacer, making more or less contact with the carbon traces on the bottom layer. This yields a pressure dependent resistance.

## PRESSURE SENSITIVE MEMBRANES

Our pressure sensitive keyboard uses a modified flexible membrane design. Unlike traditional membranes that are designed to create a simple contact closure, we create a contact that decreases in resistance as force is increased. In addition to this, we require this resistance to be large compared to the resistance of the row and column connections.

One method of accomplishing this function would be to utilize a piezoresistive material – a material that changes resistance according to pressure. The popular Tekscan FlexiForce® sensors use a piezoresistive material deposited between a top and bottom conductor [11].

The force sensor design that we chose is a simple extension of the standard keyboard membrane/dome design. As before, we have three layers – two with inward facing printing separated by an insulating spacer with holes at the key sites. On a standard keyboard, the collapsed dome deforms the top sheet through the hole to make contact with the bottom sheet. We note that if additional pressure is applied, the dome squeezes down, further deforming the top sheet into the hole. The contact region starts as a small dot in the center, and becomes a growing circular region as further pressure is applied.

The force sensor is designed to exploit this growing contact area to decrease the resistance from the top layer to the bottom layer. This is accomplished through the use of carbon ink, which is easily screen printed, and has a resistivity orders of magnitude higher than silver ink. (Carbon ink printing is a mature technology, often used to create resistors and protect silver contacts.) Figure 2 shows our design.

We felt it was very important for our Pressure Sensitive Keyboard to be an excellent keyboard first, and pressure sensitive second. We are thus using a standard dome to give the appropriate feel. The underlying membrane layers do not contact until the dome buckles. The sudden change from open circuit to resistor gives us the standard clean detection of a key press. It is only after the key is actually pressed that we detect pressure. As will be seen, this also allows for considerable power savings compared to a system that does not go open circuit in the unpressed state.

## ELECTRONICS

The Pressure Sensitive Keyboard is a matrix of variable resistors, with each resistor connecting a unique row-column pair. The goal of the electronics is to independently measure each of these resistors. This is a solved problem, although the solution may not be well known. (For an example, see [11].)

The basic idea is to drive all of the rows and columns to the same voltage, except for one column. In all other columns, the resistors have the same voltage on both ends, so no current flows. For the one special column at a unique voltage, current will flow from that column, through its resistors, into their respective rows. The task then reduces to measuring the current in each row. When this is done, the process is repeated at the next column, continuing until all columns have been read.

Figure 3 shows a conceptual schematic of the circuit. In this case, the common voltage is ground. All of the rows are connected to the summing node of ground referenced op amps, creating virtual grounds. All of the columns are tied to ground, except the column under test, which is driven to VDD. Current flows from that column, through its resistors, into the summing nodes. The outputs of the op amps move proportional to these currents. (The op amps are wired as ‘transimpedance amps” – converting current to voltage.) A multiplexed A/D convertor reads these voltages, one at a time.

Much of the time, no keys at all are pressed. To save power, a quick scan is implemented which allows the system to quickly check all of the columns in parallel to see if any key is pressed, and then return to a low power sleep until another check is required. Because the membrane design presents an open in the unpressed state, we can set all of the columns to VDD and if any current flows into a row, some key on that row is pressed. We can then proceed with a detailed check to see which keys on the row are pressed. The same trick can be used to quickly check subsections of the row.

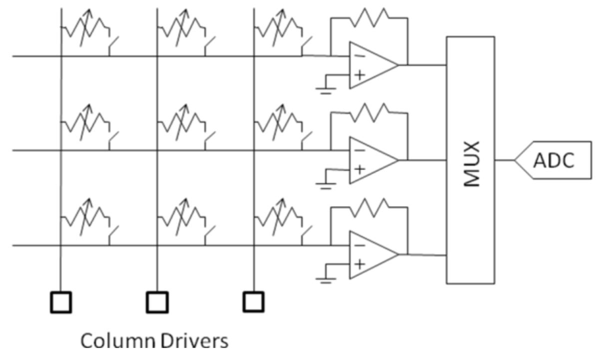

Figure 3: Matrix scan circuit.

It should be noted that this design overcomes a common keyboard problem known as “ghosting”. In standard membrane designs, pressing three keys - two on the same row and two on the same column – shorts another row to a column whether or not that key is pressed. Since some multi-key combinations are common, the matrix must be rearrange to ensure critical combinations can be detected properly. Unfortunately, this moves the problem to some other combination of keys. Gamers are often distraught to discover that certain key combinations don’t work on their keyboards. The Pressure Sensitive Keyboard not only eliminates this problem, by removing the need to rearrange the matrix, the designs are generally simpler.

## APPLICATIONS

In this section, we consider some interactions that are possible with a pressure sensitive keyboard. This list is not meant to be comprehensive – our objective is to give representative examples that will inspire others to find interesting uses.

### Gaming

An obvious application of the Pressure Sensitive Keyboard lies in computer gaming. Want to run faster? Press harder. Run slowly? Press lightly. The basic idea here is to control the intensity or degree of some keyboard function by the force level used to depress that key.

A less obvious mode of interaction involves the use of simple gestures. For example, it is possible to easily tell the difference between pounding the Num pad with a fist versus hitting it with the side of a hand. In this mode, we are using the keyboard as a low resolution, multi-touch sensor to do simple gesture recognition.

### Emotional Instant Messaging

Creative use of typography can help lend emotional impact to text [12]. Although many instant messaging programs allow users to vary font sizes, this feature is not typically used in the midst of a rapid back and forth conversation. A Pressure Sensitive Keyboard allows users to instantly convey additional emotion by mapping font size to key pressure. Figure 4 shows an example.


Figure 4: Sample output from the Emotional Instant Messenger application.

An extension of this idea is to do context dependent mappings. For example, when the word "LOVE" is typed, rather than just scaling the font size with pressure, the system can also scale the style. So typing the word gently gives ordinary text, but pressing hard both increases the font size and switches to an increasingly ornately scripted version.

### General Typing

There are many interactions that are of use in more general typing (e.g. writing a document or an email, etc.). Typematic refers to the automatic repeating of a character after a key has been depressed for some amount of time. Typically, the feature activates after a significant delay to differentiate it from normal character strikes. With a Pressure Sensitive Keyboard, the feature could be activated by striking the key hard, allowing it to start without delay. In addition, the pressure level can determine the repeat rate.

Our Emotional Instant Messaging application implemented a generically useful feature. The Backspace key deletes a single character at a time if pressed lightly, and a word at a time if pressed more forcefully. This sort of function overloading has many applications beyond instant messaging. In general, hitting a key harder to do more of that sort of function is extremely intuitive. Other examples might include pressing the arrow keys harder to scroll faster, pressing enter harder to do a page break, pressing characters harder to capitalize, bold or italicize them, etc.

A Pressure Sensitive Keyboard can also improve typing accuracy. When typing rapidly, it is common for sloppy typists to partially strike an adjacent key while hitting the desired key. The relative pressure levels can be used to help differentiate the intended key.

## ADOPTION

Earlier, we noted the difficulties in innovating in the keyboard space. The Pressure Sensitive Keyboard has a number of features that should allow it to succeed in the face of these challenges.

1) It can be manufactured at a modest premium over conventional keyboards.
2) It looks and feels exactly like a regular keyboard.
3) Pressure sensitivity can be enabled in software, allowing users to adapt at their own pace.

This last point is an important one. In our informal testing, a number of users spontaneously commented that they would "buy that keyboard just for…" one feature from the demonstrations.

Our informal testing of the Emotional Instant Messaging demo indicated that people very quickly learn to control their typing pressure to a reasonable degree. This is consistent with the results from [3].

## CONCLUSION

We have presented a practical Pressure Sensitive Keyboard that can be inexpensively mass-produced and given some sample applications. It is our hope that this work will inspire other researchers to explore the interaction possibilities of these devices.

## ACKNOWLEDGMENTS

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