Small, Low-profile Keyboard That Does Not Impair Operability

●Goro Watanabe   ●Tamotsu Koike   ●Hideyuki Motoyama
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This paper introduces a method of miniaturizing a keyboard while maintaining its operability. Two techniques have been developed. The first is a new gear link mechanism for the key switches which results in a keyboard that is approximately 40% thinner with no decrease in the stroke distance. The second technique involves reducing the vertical key spacing while maintaining the horizontal key spacing at 19.05 mm. Subjects having little experience with conventional keyboards preferred 17.05 mm and 15.05 mm spacings over a 19.05 mm spacing.

1.   Introduction

In recent years, following the introduction of the Graphical User Interface (GUI), new input devices such as mice and pens have been developed. However, there is currently no satisfactory replacement for the keyboard, which remains the most common input device for the human computer interface.

The use of mobile computers, which must be small, thin, and light, is expanding rapidly. Devices mounted on the inside and outside of mobile computers must therefore be made smaller. Since the keyboard occupies a proportionally large area, the effect of making it thinner and smaller is obvious. However, any reductions in the stroke distance and key spacing will affect the operability. Therefore the problem in keyboard development is to reduce the keyboard size without sacrificing operability.

We have developed a new key switch mechanism that reduces keyboard thickness but retains a sufficient key stroke distance. Also, we have found that by reducing the vertical key spacing while keeping the horizontal spacing at the 19.05 mm standard, we can produce a smaller keyboard with no loss in operability.

2.   Technologies for reducing keyboard thickness

It is very important that a keyboard has a good key touch feeling (e. g., a suitable tactile feedback, smooth movement, and sufficient key stroke distance). Generally the optimal key stroke distance is proportional to the key spacing. (A full-size keyboard with a 3/4-inch [19.05 mm] key spacing usually has a key stroke distance of from 3 mm to 5 mm). A simple way to reduce keyboard thickness is to use keys with a short stroke distance; but for good operability, a suitable key stroke is needed. We therefore decided to develop a method of reducing the keyboard thickness while maintaining a suitable stroke.

2.1 Conventional key switch
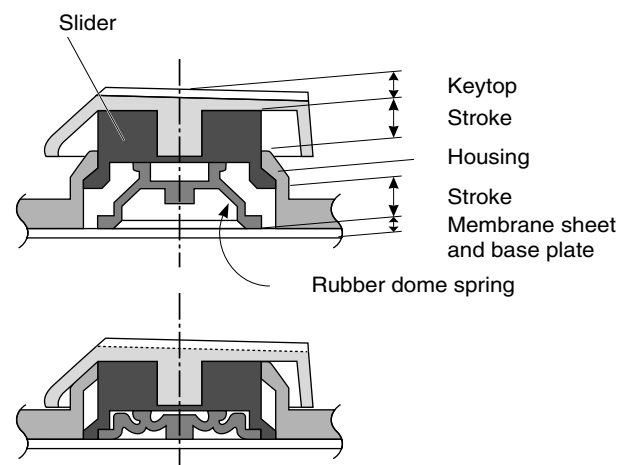
Figure 1 shows the conventional key switch.

Figure1.
Conventional key switch structure.

Most conventional keyboards use this type of key switch. This key switch basically consists of a key top, slider, housing which guides the slider, rubber dome spring, membrane sheet switch, and baseplate. When the key top is pressed, the slider compresses the rubber dome spring and closes the membrane sheet switch. The distance that the key top moves up and down is the key stroke. For this structure, it is easy to achieve a good operability. However, two spaces are needed for the slider to move. In addition, for good tactile properties, the slider and the housing must overlap each other when the switch is in the relaxed state. As a result, a keyboard with a 3 mm stroke is usually more than 11 mm high.

2.2 Development of a low-profile keyboard

Figures 2 and **3** show our new key switch, which is based on a gear link method. This switch meets our main development target, which was to produce a switch whose key top stays parallel to the base plate as it is pressed (i.e., does not tilt) and takes up the minimum amount of vertical space. Each key switch has two gear links. The top ends of the gear links are fixed to the key top and are free to rotate, while the bottom ends slide horizontally on the membrane sheet surface. The two gear links are coupled via a system of gears.

Because our new key switch eliminates the slider spaces and overlap, a keyboard of these key switches is approximately 40% thinner (total thickness is 6.8 mm) than conventional keyboards.

3. Miniaturization technique

For good ergonomics, a key spacing of 19.05 mm is usually recommended.[1]

With the QWERTY keyboard, when the operator pauses, the index finger of the left hand is on the F key and that of the right hand is on the J key. These pause positions are called the home positions for the relevant fingers.

The ideal horizontal key spacing depends on the finger spacing when the fingers are in the
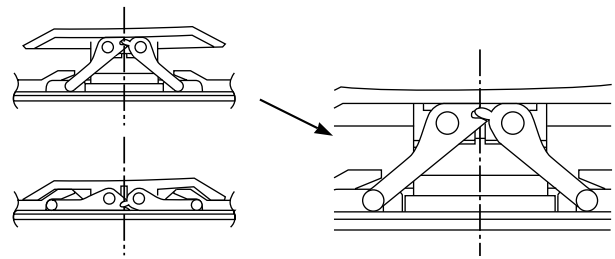

Figure 2.
Gear link key switch.

① Keytop
② Housing
③ Gear link
④ Rubber dome spring
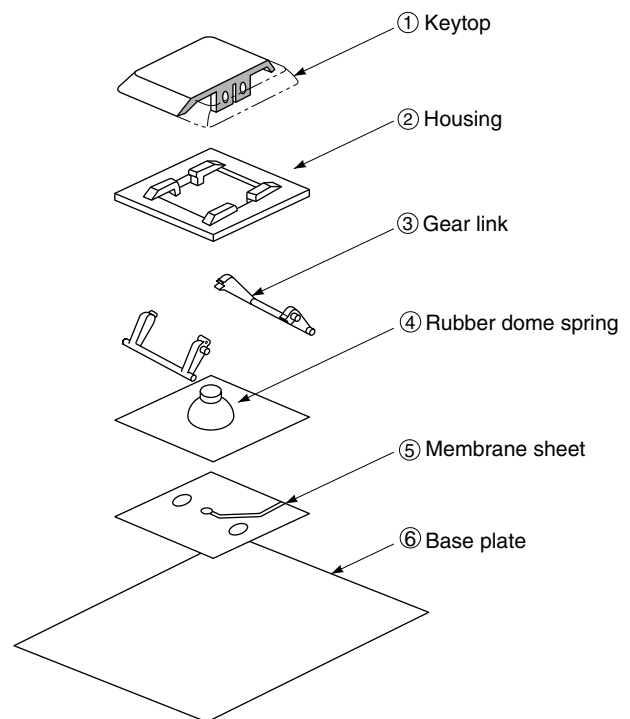⑤ Membrane sheet
⑥ Base plate

Figure 3.
Components of gear link key switch.

home positions. On the other hand, the ideal vertical key spacing depends on the distance the fingers move. Therefore, the vertical spacing and horizontal spacing must be tackled separately.

Because the distance between fingers is mostly constant, the horizontal key spacing cannot be changed. On the other hand, because reducing the vertical key spacing reduces the distance each finger must move, we can expect that such a reduction will improve the ease of use.

We therefore constructed a keyboard with the standard horizontal spacing and an adjustable

vertical spacing and then subjected it to various objective and subjective evaluations.

3.1 Evaluated keyboard

The keyboard had alphabetic, numeric, tab, right shift, left shift, caps lock, backspace, and enter keys. Keys which were not directly related to the input of romanized Japanese sentences were omitted. The key arrangement of the Japanese keyboard used in conventional AT personal computers was used. The horizontal key spacing of this keyboard was the standard 19.05 mm. The vertical spacing was adjustable to 19.05 mm, 17.05 mm, 15.05 mm, and 13.05 mm.

3.2 Evaluation procedure

The characteristics shown in **Table 1** were evaluated. The keyboard was connected to a personal computer through a normal keyboard interface. Software was used to record the characters that were input on the keyboard and displayed on the console. The evaluations were conducted as follows using two groups of subjects:

1) The subjects described their first impressions of the keyboard in a questionnaire before beginning to type.
2) The subjects were given a set of Japanese sentences written in the Japanese syllabary and then asked to type in the sentences in their romanized form for one minute. The number of characters typed in this period varied slightly between subjects, but in their romanized form they amounted to about 400 characters.
3) The subjects completed a questionnaire concerning the ease of use.
4) Steps 1 to 3 were repeated for the other spacings.
5) The subjects took a short rest, then began the second set.
6) In the second set, the subjects completed the input work and questionnaires for the other spacings.
7) The subjects were asked to comment on the

Table 1. Evaluated characteristics.

	Item	Measurement
Objective evaluation	Input speed	Number of characters input in 5 seconds
	Error rate	Input error rate
Subjective evaluation	Overall preference	Ease of use according to a seven-step scale

ease of use, to choose their favorite spacing, and to state the reasons for their choice.

Each subject tested the spacings in a different order to exclude any effects the order might have had on the results. The input sentences were different in each trial, and the combinations of sentences and keyboard spacings were random for each subject.

3.3 Subjects

There were 16 subjects in the evaluations. **Figure 4** and **Table 2** show the distributions of key stroke speeds in each group. In Figure 4, the boxes show the ranges from the 25th (LQ) to the 75th (UQ) percentile of the data. The lines in the boxes show the median. The ends of the vertical lines show the maximum and minimum values, which are in the range from LQ-1.5(UQ-LQ) to UQ+1.5(UQ-LQ).

The subjects were divided into two groups depending on whether they typed daily in their work. Those who did were placed in the skilled group, and those who did not were placed in the unskilled group. The keystroke speed was the average number of characters input in five seconds. **Table 3** shows the t-value and 2-tail significance between the input speeds of the two groups. The mean keystroke speed was significantly faster in the skilled group compared with the unskilled group. The subjects were divided into the skilled and unskilled groups because of the clear differences in typing skills.

3.4 Evaluation results
3.4.1 Objective evaluation

The objective evaluation was based on two

Table 2. Input speeds of subjects (characters/5 seconds).

Group	Mean	Standard deviation
Skilled	21.271	6.006
Unskilled	11.656	3.263

Table 3. Results of t-test between speeds of skilled and unskilled groups.
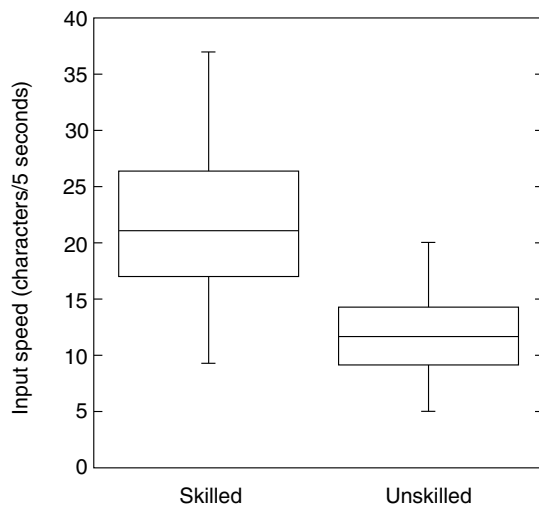
t-value	2-tail significance
13.782	0.000

Figure 4.
Input speeds of skilled and unskilled groups.

Table 4. Mean keystroke speeds and error rates.

Group	Set No.	Item	Significant differences	2-tail significance
Skilled	Set 1	Keystroke speed	None	–
		Error rate	None	–
	Set 2	Keystroke speed	19.05 mm faster than 13.05 mm 17.05 mm faster than 13.05 mm	0.007 0.02
		Error rate	None	–
Unskilled	Set 1	Keystroke speed	17.05 mm faster than 13.05 mm	0.007
		Error rate	19.05 mm better than 13.05 mm	0.045
	Set 2	Keystroke speed	None	–
		Error rate	None	–

parameters: the mean keystroke speed and the input error rate. **Table 4** shows the evaluation results for all trials of the skilled and unskilled groups. The results for the 13.05 mm spacing were inferior to those for the other spacings; however, there were no significant differences between the other spacings. This means that, in terms of input ability, the same performance can be expected for all spacings except the 13.05 mm spacing.

3.4.2 Subjective evaluation

Next, the members of the two groups were asked to make a subjective evaluation of the four spacings. **Figures 5** to **7** show the overall evaluations of the skilled group in the first impression stage, after the first set, and after the second set, respectively. **Table 5** shows associated data. In the first impression stage, the skilled group preferred the 19.05 mm and 17.05 mm spacings to the 15.05 mm and 13.05 mm spacings. However, after the first set, there was a marked nonpreference only for the 13.05 mm spacing. Then, after the second set, the evaluations of both the 13.05 mm spacings and the 15.05 mm spacings were lower than those of the 19.05 mm spacing.

The figures show that in the skilled group, the 19.05 mm spacing, which is the standard, was especially popular, their evaluation of the 15.05 mm spacing was variable, and the 13.05 mm spacing had an overall low evaluation.

Figures 8 to **10** show the overall evaluations of the unskilled group in the first impression stage, after the first set, and after the second set, respectively. As shown in **Table 6**, in the first impression stage, the 19.05 mm and 17.05 mm spacings were preferred over the 13.05 mm spacing. There were no preferences between the other spacings. These evaluations were similar to those of the skilled group. However, after the first set, all key spacings were given the same evaluation. After the second set, the 17.05 mm spacing was preferred over the 19.05 mm and 13.05 mm spacings.
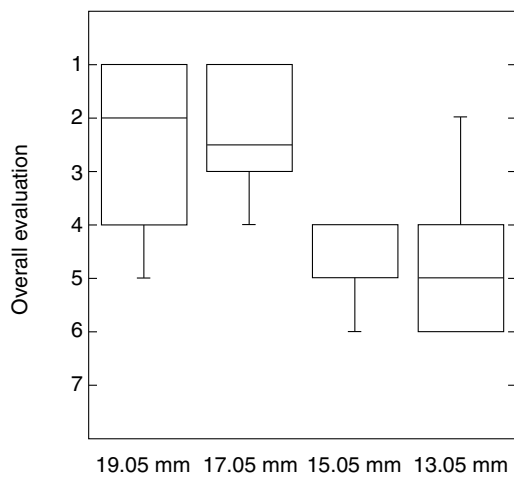
Figure 5.
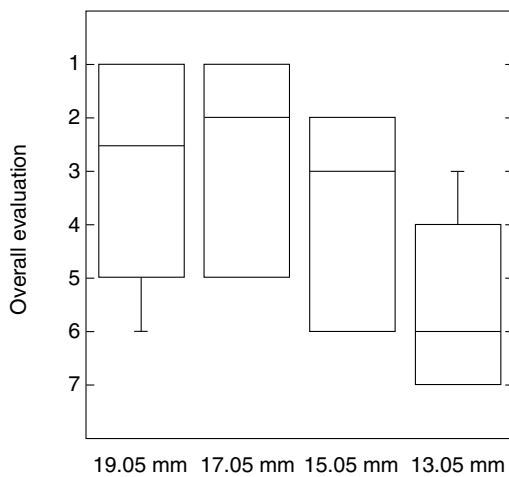Overall evaluations of skilled group (first impression).

Figure 6.
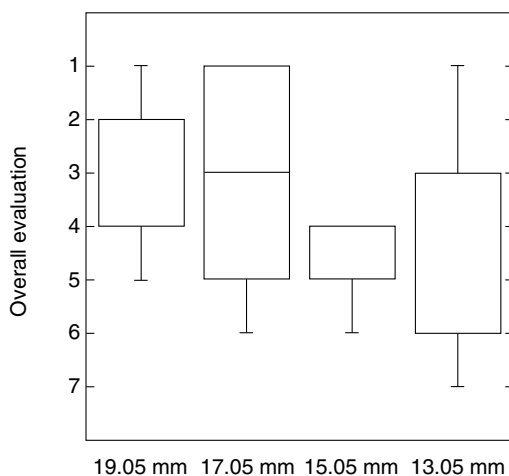Overall evaluations of skilled group (after first set).

Figure 7.
Overall evaluations of skilled group (after second set).

Table 5. Data for overall preferences (skilled group).

Set No.	Preferences	2-tail significance
First impression	17.05 mm better than 13.05 mm	.004
	19.05 mm better than 13.05 mm	.013
	17.05 mm better than 15.05 mm	.005
After set 1	15.05 mm better than 13.05 mm	.011
	17.05 mm better than 13.05 mm	.005
	19.05 mm better than 13.05 mm	.017
After set 2	19.05 mm better than 13.05 mm	.017
	19.05 mm better than 15.05 mm	.040

These results are very interesting. The skilled and unskilled typists both preferred the standard spacing in the first impression stage (before they used the keyboard). However, their evaluations differed as the trial proceeded. Finally, the unskilled typists preferred the 17.05 mm spacing, which is smaller than the standard spacing of 19.05 mm. This suggests that a spacing slightly smaller than the standard one might be suitable for unskilled typists.

3.5 Discussion

The previous paragraph and the results of the objective evaluations suggest that the 13.05 mm spacing was unpopular with both the skilled and unskilled groups. The results for spacings other than 13.05 mm are given below. The term "narrow spacings" used here means the 17.05 mm and 15.05 mm spacings.

Table 7 shows the results of the interviews conducted at the end of the evaluations. In the skilled group, six out of eight said that the narrow key spacings were mediocre or unsatisfactory. The reason they gave for their evaluations was that it was more difficult to strike the keys because they were shifted from their usual positions. On the other hand, six of the unskilled group said
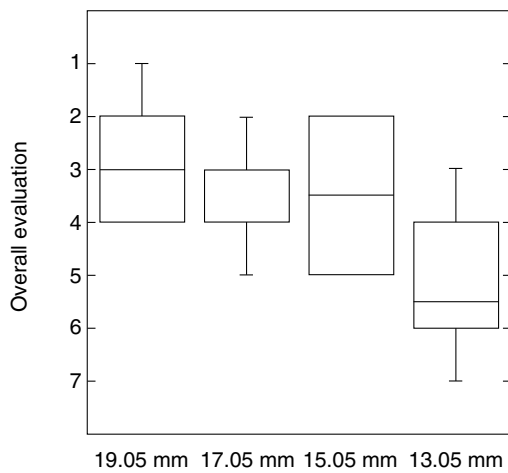
Figure 8.
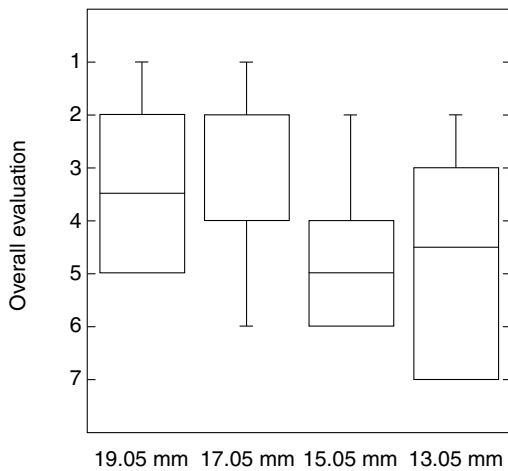Overall evaluations of unskilled group (first impression).

Figure 9.
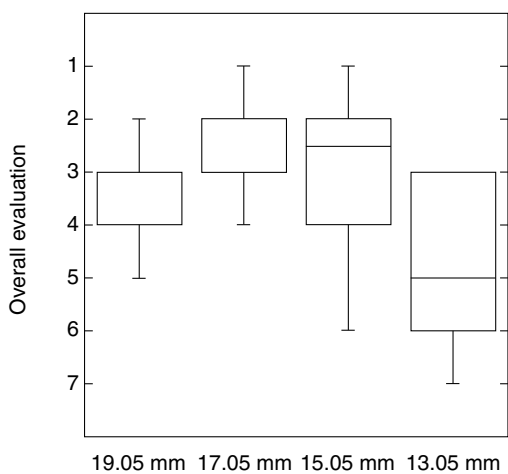Overall evaluations of unskilled group (after first set).

Figure 10.
Overall evaluations of unskilled group (after second set).

Table 6. Data for overall preferences (unskilled group).

Set No.	Preferences	2-tail significance
First impression	17.05 mm better than 13.05 mm	.006
	19.05 mm better than 13.05 mm	.020
After set 1	None	
After set 2	17.05 mm better than 13.05 mm	.024
	17.05 mm better than 19.05 mm	.049

Table 7. Results of interviews about the narrow key spacings.

Evaluation	Skilled group	Unskilled group	Total
Very good	1	5	6
Good	1	1	2
Mediocre	3	0	3
Unsatisfactory	3	2	5

that the narrow spacings were good or very good because they did not need to extend their fingers since the keys were nearer than usual.

We concluded that the skilled group was accustomed to the standard spacing, which biased their evaluation of smaller spacings. Their judgment was based on whether the keyboard had the standard spacing, and consequently they discriminated against the narrow spacings. On the other hand, the unskilled group did not use the standard spacing as a criterion because they were unaccustomed to the standard keyboard. That is, they evaluated all spacings based solely on the operability. As a result, they preferred the narrow spacings over the standard one.

This suggests that the preferences of the skilled group were not based on operability, and that based solely on operability, users would prefer the narrow spacings over the standard spacing.

4. Conclusion

This paper described a way to make keyboards thinner and smaller.

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Table 8. Specifications of new keyboards.

	Application	Height	Key stroke	Key spacing
FKB7600 series	Thin note book PC	6.8 mm	3.0 mm	19.05 × 19.05 mm
FKB7650 series	HPC/Mobile PC	5.8 mm	2.0 mm	15.0 × 14.0 mm

First, a new gear link mechanism for key switches was introduced that reduces the keyboard's thickness by 40% with no reduction in stroke distance. As a result, a keyboard can be made thinner while retaining its operability.

Then, the results of experiments on a keyboard that had a reduced vertical key spacing and the standard 19.05 mm horizontal key spacing were presented. We found that subjects unskilled with a conventional keyboard preferred 17.05 mm and 15.05 mm vertical spacings over a 19.05 mm spacing. Our experiments indicated that our miniaturization technique is effective and does not impair operability.

We have developed two small keyboards based on our new gear link structure and the findings reported in this paper. **Table 8** shows the specifications of these keyboards. The FKB7600 and FKB7650, at only 6.8 mm thick, are approximately 40 % thinner than conventional keyboards. The FKB7650 was miniaturized by changing the key spacing from 15.0 × 15.0 mm to 15.0 (horizontal) × 14.0 mm (vertical) without affecting the operability. Although this keyboard had a smaller horizontal spacing than the standard spacing, our miniaturization technique was still effective.

The search for thinner, smaller keyboards and other devices continues. Further technological innovation regarding key switch structure will be an important part of the search.

Reference

1) JIS X 6041: CRT Display and Keyboard Units for Business Use, 1987.

Goro Watanabe received the M.S. degree in Mechanical Engineering from Kyoto Institute of Technology, Kyoto, Japan in 1992.
He joined Fujitsu Laboratories Ltd., Kawasaki in 1992, where he has been engaged in research and development of keyboards.

Tamotsu Koike graduated from Nagano Technical High School, Mechanical Engineering dept., Nagano, Japan in 1984.
He joined Fujitsu Ltd., Kawasaki in 1984, where he has been engaged in mechanical design and development of keyboards and pointing devices.

Hideyuki Motoyama received the M.S. degree in Electronic Engineering from Tottori University, Tottori, Japan in 1990.
He joined Fujitsu Laboratories Ltd., Kawasaki in 1990, where he has been engaged in research and development of keyboards.