Online Handwriting Recognition Technology and Its Applications

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This paper describes Fujitsu's online handwritten character recognition (OLCR) technology and some application software that adopts this technology. Fujitsu's Japanese OLCR has the highest level of performance among Japanese OLCRs and is based on two of our unique character recognition technologies: hybrid character recognition and bigram-based context processing. To realize more effective and practical handwriting interfaces, we have developed additional OLCR techniques such as hybrid adaptation, predictive handwriting recognition, and box-free handwritten string recognition. Several software products, including Japanist 2003 and Japanist for Pocket PC, have adopted this technology. This technology is also used by the standard handwriting recognition engine in FMV-STYLISTIC, which is one of Fujitsu's Tablet PCs. In one experiment, our OLCR technology achieved a 94.6% recognition accuracy for Japanese text compared to other software available on the market, which achieved an accuracy of only 82 to 88%.

1. Introduction

The recent development of new algorithms has made it possible to achieve practical Japanese online handwritten character recognition (OLCR). Although the new algorithms are generally more complex than the old algorithms, recent improvements of CPU performance make them suitable for practical use. Because of the realization of practical performance, OLCR is becoming a common input method, especially in the growing area of pen-input equipment such as Palm, Zaurus, Pocket PC-based PDAs, and Tablet PCs. Fujitsu has one of the highest performance OLCRs and some unique pen-input interface technologies.

Handwriting recognition is suitable for mobile situations, in which keyboards cannot easily be used. An alternative might be keypad input, using key buttons on cell phones, or software keyboards on PDAs. Recently, the effectiveness of keypad input has been improved by predictive functions.[1] Similar functions can be used for OLCRs to improve Fujitsu OLCR technology, although it is already much better than most of the other OLCRs.

In this paper, we describe Fujitsu's OLCR technology.[2] We first explain hybrid character recognition[3] and bigram-based context processing, which are the basic elements of this technology.[4] We then describe additional features of our OLCR such as hybrid user adaptation,[5),6] handwriting prediction,[7] and box-free handwritten string recognition.[8),9] Next, we introduce some of the software products we have developed for use mainly on Tablet PCs and Pocket PCs. We also describe an experiment in which we compared our OLCR with other text-input software. This experiment showed that our OLCR not only has a superior recognition accuracy but also that users prefer it to the other software. These results suggest that our technology is superior to the other

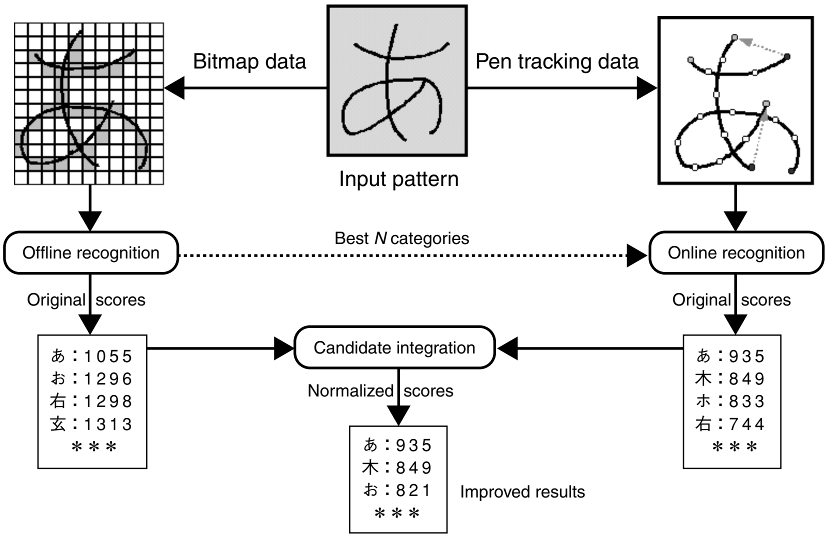


Figure 1
Hybrid character recognition.

software we tested.

2. Fujitsu's OLCR technology

Fujitsu's OLCR technology realizes high recognition performance based on a unique method of hybrid character recognition and a bigram-based context processing. It also has the following features: hybrid adaptation, handwriting prediction, and box-free handwriting string recognition. These features make our OLCR technology more efficient and practical.

2.1 Hybrid character recognition[3)]

Hybrid character recognition has a high recognition performance, even when the pattern is input with significantly different stroke orders, stroke numbers, and character shapes. It achieves this by integrating two types of recognition algorithms: online recognition and offline recognition. The recognition object of online recognition is a time sequence of 2-dimensional points that mark the motion of the pen tip. Although the writing order provides useful and distinctive information, it is not so stable and has more variation than we could previously store in the recognition dictionary. Therefore, online recognition has a higher recognition accuracy, but it can cause unexpected mis-recognitions. On the other hand, because offline recognition uses a bitmap pattern as the recognition object, it is not affected by variations in the stroke writing order of the input pattern. Although the peak recognition accuracy of offline recognition is inferior to that of online recognition, it can complement the weakness of online recognition by integrating two types of recognition method (**Figure 1**).

2.2 Bigram-based context processing

One of the most important issues in OLCR is how to recognize similar characters that cannot be distinguished just by their shapes (e.g., how to distinguish between the number "1", symbol "/", and a vertical bar "|"). Bigram-based context processing discriminates between similar characters using the transition probability of a continuous pair of characters.

2.3 Hybrid adaptation

We developed two user adaptation methods that acclimatize the OLCR engine to the user's writing style. These methods are called adaptive context processing[4)] and adaptive classification.[5)] We then developed a unique method called hybrid adaptation, which integrates these two methods

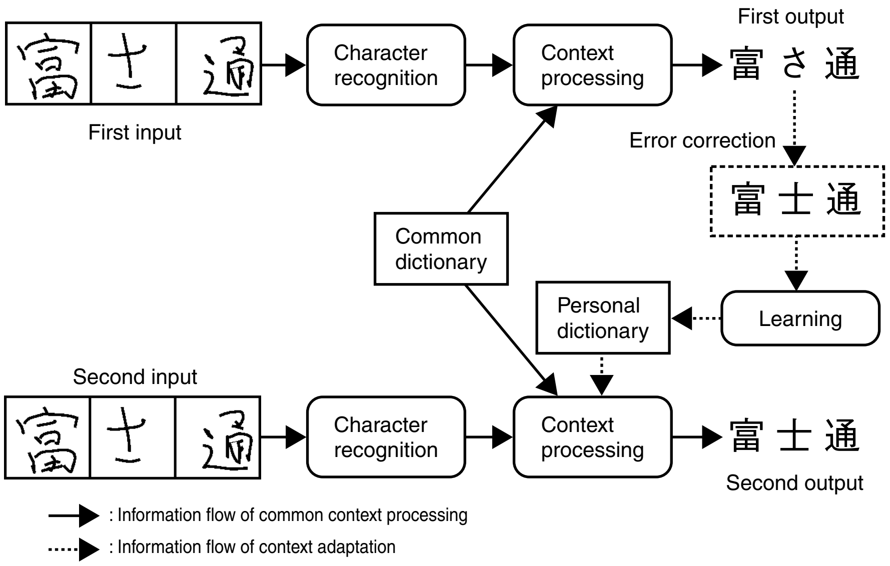


Figure 2
Adaptive context processing.

to improve the recognition performance.[6)]

2.3.1 Adaptive context processing[4)]

Adaptive context processing (ACP) stores user terms (sub-strings) extracted from the previously input string and then improves the recognition accuracy by giving priority to the stored terms. As shown in **Figure 2**, once an error is corrected (from 富さ通 to 富士通 for the first input), recognition errors of subsequent similar inputs are avoided by referring to the personal dictionary containing the correct string (富士通). ACP prevents repeated mis-recognitions and also avoids the risk of user stress caused by repeated failures.

2.3.2 Adaptive classification[5)]

Adaptive Classification (ACL) stores user input patterns and then improves recognition accuracy by modifying the classification dictionary. ACL also reduces repeated mis-recognitions.

Although most of the common adaptive classification methods automatically store user-handwritten patterns into a classification dictionary to rectify mis-recognitions, they may unexpectedly influence another character's classification. To prevent negative influences, we have developed a new adaptive classification method called Discriminating Template Transformation (DTT), which transforms input patterns before they are stored (**Figure 3**).

Figure 3 (a) shows a discrimination space in which input pattern C is wrongly classified as class-A because it is closer to A-2 than B. However, by modifying the newly registered pattern A-2 as A-2' as shown in Figure 3 (b), the incorrect classification of input pattern C can be corrected.

2.3.3 Hybrid adaptation[6)]

Our new hybrid adaptation method is shown in **Figure 4**. **Table 1** shows evaluation results for data taken from a handwritten character database in which 84.8% of the characters exist in multiple locations and 13.5% of the characters are duplicated strings. The experiment was carried out by inputting the same database twice. The results show that hybrid adaptation has a higher performance than adaptive context processing and adaptive classification.

2.4 Predictive handwriting recognition[7)]

To enhance input efficiency, we have devel-

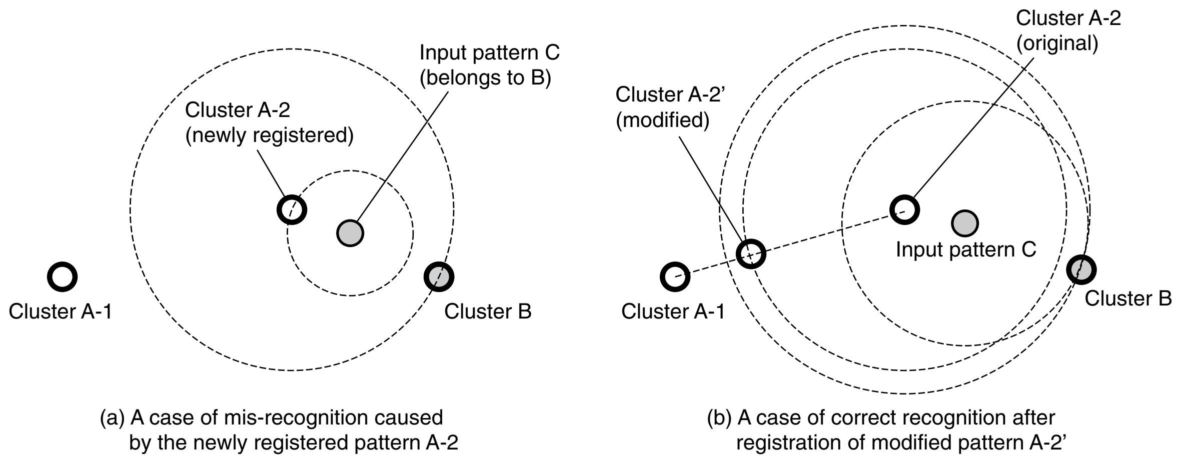


Figure 3
Adaptive classification.

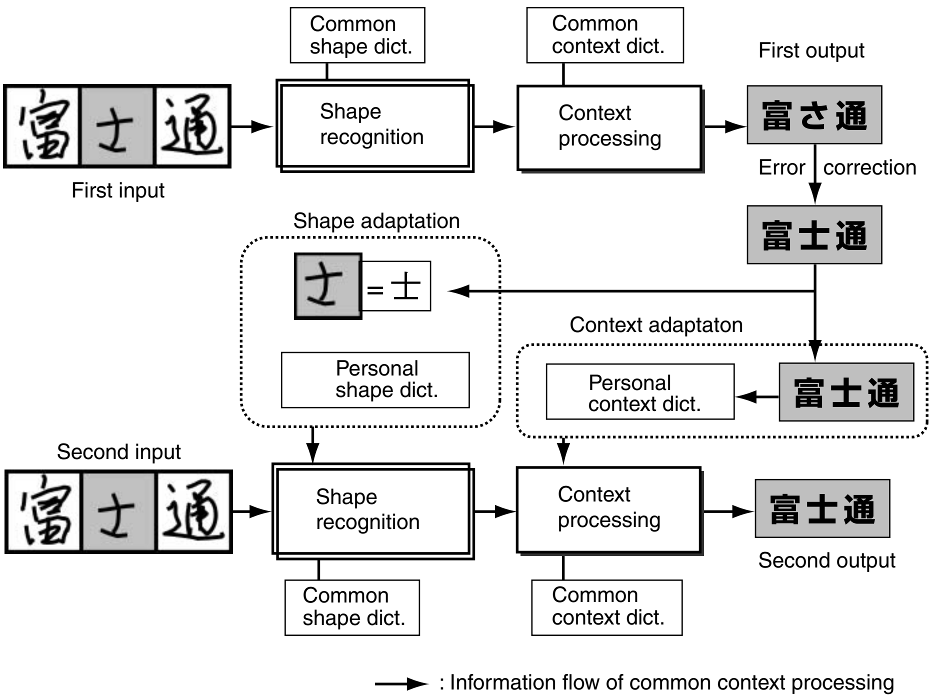


Figure 4
Hybrid adaptation.

oped a predictive handwriting recognition technology. The conventional prediction method often used by keypads predicts input strings by comparing sub-strings with each entry in a prediction dictionary. When handwriting recognition is used as an input method, the conventional method occasionally fails to predict when certain characters will be mis-recognized. To solve this problem, we developed a new prediction method that uses recognition candidates that include second and lower entries to predict the input string, even if some characters are mis-recognized.

Table 2 shows the results of an experiment that compared handwriting input with and without our prediction method. There were 10 test subjects in the experiment. Using the prediction method, both the average input time and average number of written strokes were reduced by half.

Table 1
Hit rates for handwritten character database.

(Unit : %)

Experiment cycle	First	Second
Non-adaptation	93.3	93.3
Adaptive classification	94.8	95.3
Adaptive context processing	93.8	97.9
Hybrid adaptation	95.1	99.0

Test data: HANDS_kuchibue_d-97-06 (10 154 patterns, 120 subjects)
Dictionary: 6875 characters (including all the JIS1-2 kanji)

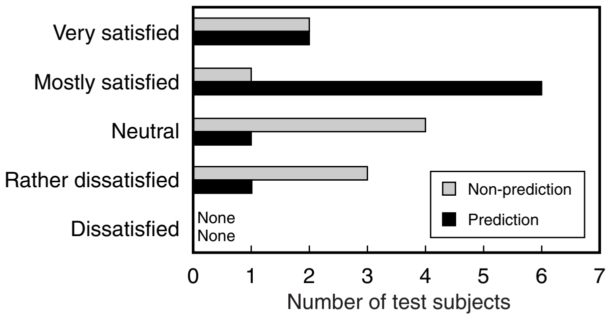


Figure 5
Users' satisfaction with and without prediction.

Table 2
Input time and operation count of handwritten input.

		Without prediction	With prediction
Average input time		11 min 33 s	6 min 8 s
Average operation count	Written strokes	170	43
	Average number of selections made to predict a word	0	43.1

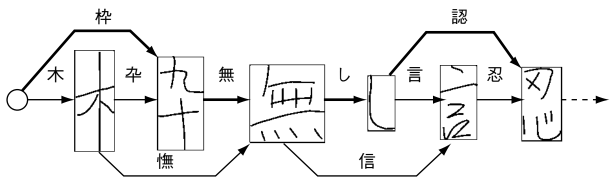


Figure 6
Basic idea of box-free handwriting recognition.

Our handwriting prediction method, therefore, almost doubles the input efficiency compared to non-prediction input. Also, after the experiment, the test subjects mostly told us they preferred using our method (**Figure 5**).

2.5 Box-free handwriting string recognition[8),9)]

To realize more natural handwriting input, we have developed a box-free handwriting string recognition technology that can recognize handwritten characters without the need for a writing box. With the box-free method, users can write characters in different sizes and positions, just as they do when writing on real paper. In an experiment with 100 test subjects, 66% of the subjects preferred a box-free handwriting style to a box-based style and only 26% chose a box-based style.[8)]

Box-free handwriting recognition creates many small blocks from input string patterns and then makes an appropriate string by connecting these blocks (**Figure 6**). Although most box-free methods require several times the calculations performed by box-based methods, our method can respond quickly and provides a recognition result immediately after a character has been input.

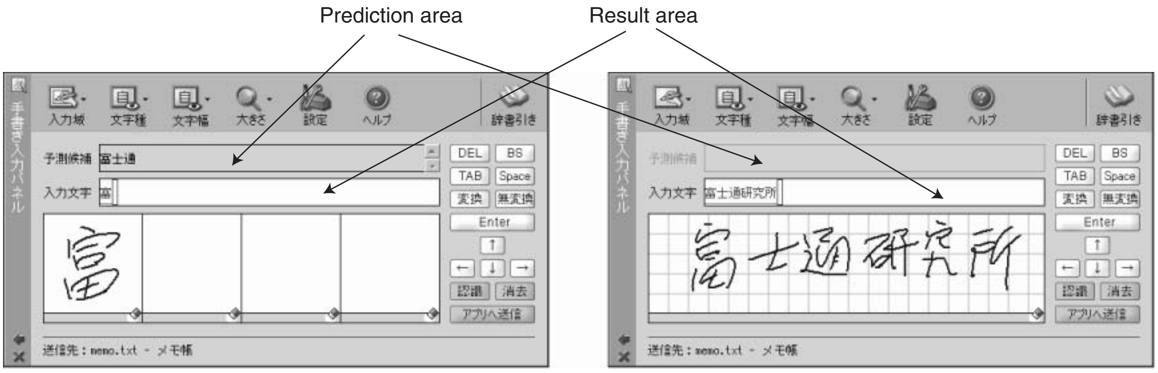
3. Applications

Fujitsu's OLCR technology is used in various software products. We will now explain Japanist 2003, which is a Japanese input software for Windows and Japanist for Pocket PC, which is a handwriting character recognition software for Pocket PCs. We also introduce another OLCR software for PDAs that we are developing.

3.1 Japanist 2003

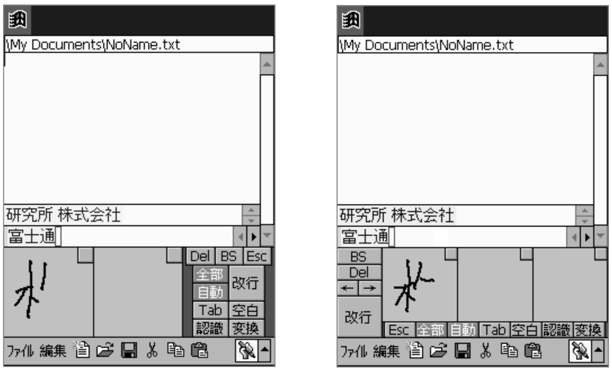
Japanist is a Fujitsu Japanese input software that includes a kana-kanji conversion (KKC) function and a dictionary search function. The latest version of Japanist (Japanist 2003: released in February 2003) contains a handwriting input panel that employs our OLCR technology.

Japanist 2003 has two input modes in the handwriting input panel (**Figure 7**). In the writing-box mode, written characters are recognized one by one and the text result is displayed in the result area. If there are predicted terms, they are



(a) Writing-box mode (b) Box-free mode

Figure 7
Handwriting input panel of Japanist 2003.



(a) Default design (b) Example of customized GUI (3 boxes, left buttons)

Figure 8
Japanist for Pocket PC.

displayed in the prediction area above the result area. In the box-free mode, the written characters are recognized all together after they have been input. The recognition result is displayed in the result area, as in the writing-box mode. However, the prediction function does not work in the box-free mode. Because both of these input modes adopt hybrid adaptation, the recognition accuracy increases as the user continues to use the software.

Although Japanist 2003 works on most of the recent versions of Windows (NT4.0/2000/98/XP), the handwriting input panel is more suitable for use with a Tablet PC, which can be used primarily with pen input.

3.2 Japanist for Pocket PC

Japanist for Pocket PC is an OLCR software for Pocket PCs (**Figure 8**). It has almost the same performance as the writing-box mode of the Japanist 2003 handwriting input panel. Because it conforms to the text input framework specification for Software Input Panels (SIPs), it works as part of the common text input method on Pocket PCs. In addition to the basic OLCR functions, it provides a customizable graphical user interface (GUI). For example, the colors, number of writing boxes, and button positions can be changed according to the user's preferences. Japanist for Pocket PC has been shipped as attached software with Fujitsu's Pocket LOOX Pocket PC since January 2003.

3.3 Realtime box-free handwriting recognition GUI for PDAs

Next, we describe another OLCR software for PDAs with which users can write strings freely and continuously. This software is now in the research phase.

Because writing boxes use a large display area, they may make it difficult to input on a small display device such as a PDA. To reduce the required amount of display area, we are developing an experimental, box-free OLCR software that does not use writing boxes.

However, box-free input technology has an-

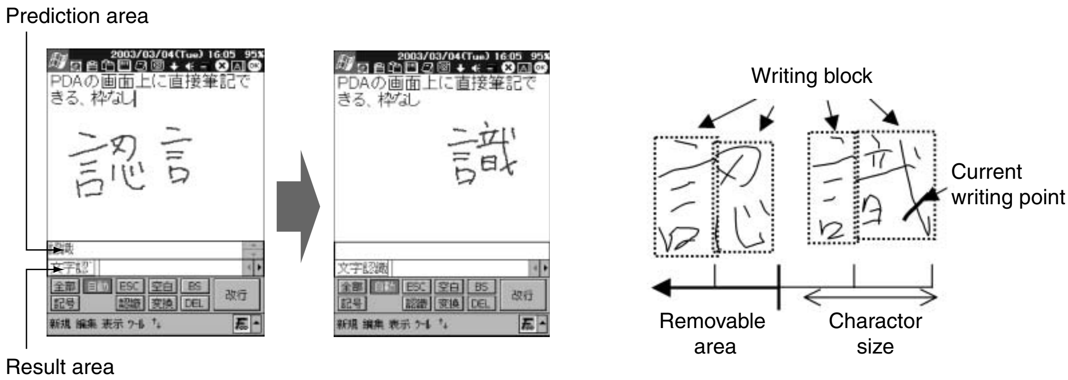


Figure 9
Realtime box-free handwriting recognition GUI for PDAs.

other difficulty. Because existing box-free OLCRs, for example, Japanist 2003, recognize an input string after all the characters have been written, the user can only write a small number of characters at a time on a small display. To input more characters, our OLCR prototype automatically hides previously input patterns as the next characters are being written (**Figure 9**). Additionally, since the prototype also has a predictive function, it can be used effectively with a small number of input characters in the same way as Japanist for Pocket PC.

In the next step, we will evaluate the recognition accuracy and users' impressions of the new software. Based on the results of the evaluation, we hope to realize a more practical handwriting input interface.

4. Comparative evaluations of Fujitsu's handwriting recognition program

To evaluate the market position of our technology, we compared the performance of our OLCR with other text-input software. We tested the recognition accuracy by comparing it with other OLCR software and then evaluated the usability of our OLCR and other text input methods. In addition to evaluations on PDAs, we did a small comparative evaluation between our OLCR and the standard OLCR for Tablet PCs.

Table 3
Recognition accuracy.

(Unit: %)

	Fujitsu	A	B	C
Total	**91.4**	82.4	76.2	83.5
Japanese	**94.6**	84.5	82.6	88.0
Alphanumeric	**85.4**	78.3	63.9	75.1

Text data: 200 Japanese characters + 107 alphanumeric characters
Subjects: 102 persons (53 male + 49 female)

4.1 Evaluation of recognition accuracy

We compared Japanist for Pocket PC with three other types of OLCR software for Pocket PCs and PDAs, all of which use writing boxes. The experiment involved 102 test subjects (53 males and 49 females) who wrote 200 Japanese characters and 107 alphanumeric characters. **Table 3** shows the first-hit rate of each OLCR software. Additionally we recorded the test subjects' impressions of the recognition performance of each software (**Table 4**). We did not use user adaptation or predictive functions to compare the recognition accuracies themselves.

The recognition accuracy of Japanist for Pocket PC was 91.4%. This is an extremely high score compared with the other software's accuracies, which were from about 76 to 83%. The percentage of test subjects who said they were satisfied with Japanist for Pocket PC's recognition performance was 67.6%. This score is also much higher than that for the other software, which ranged

Table 4
Users' satisfaction levels.

(Unit: %)

	Fujitsu	A	B	C
Satisfied (5, 4)	**67.6**	16.7	22.5	25.5
Neutral (3)	**18.6**	33.3	22.5	34.3
Dissatisfied (2, 1)	**12.7**	50.0	54.9	40.2

Based on the results of questionnaires given to the subjects

[dissatisfied 1 2 3 4 5 satisfied]

Table 5
Total time for input text.

	Fujitsu	Method A	Method B
First round	**12 min 28 s**	13 min 29 s	13 min 7 s
Second round	**6 min 51 s**	10 min 26 s	10 min 31 s

Text data: 200 Japanese characters + 107 alphanumeric characters
Subjects: 100 persons (50 male + 50 female)
Method A: Soft keybord + kana-kanji conversion with prediction
Method B: Handwriting recognition + kana-kanji conversion

Table 6
Preferred input method.

(persons)

Fujitsu	Method A	Method B	Cannot judge	None
75	30	4	3	7

note) This questionnaire allowed duplicate answers.

from about 16 to 25%. Even though it was a small experiment, we think it shows the superiority of Japanist for Pocket PC compared to the other software.

4.2 Evaluation of input efficiency

We also carried out another text-input experiment that compared the input efficiency of three types of text input methods; Japanist for Pocket PC, method A, and method B. In this experiment, the handwriting prediction function of Japanist for Pocket PC was enabled. Method A is not a handwriting input method; it uses a software keyboard and KKC software that has a string prediction function. Method B is another type of OLCR software that does not have a prediction function. The test subjects could use KKC software (MS-IME) to convert a Japanese kana string into a kanji string if they needed to use it. MS-IME does not have a prediction function and is a different KKC software from the KKC software used by method A.

Table 5 shows the input time of each round. In the first round, Japanist for Pocket PC required the shortest amount of time to input text, although the differences were not very big. However, the differences in the second round were much bigger. We think this may have been due to the effect of handwriting prediction in Japanist for Pocket PC. The reduced input times in the second round for the other software may have occurred because the subjects became accustomed to the text input methods.

We asked the test subjects which types of input method they preferred, and Japanist for Pocket PC was the most popular (**Table 6**). Because the number of test subjects who preferred Japanist for Pocket PC was almost twice the number who preferred method A, we think we have produced an OLCR technology that is more useful than a keypad.

5. Conclusion

We have developed a more practical online handwriting character recognition (OLCR) technology based on existing Fujitsu OLCR technology by adding the following new features: hybrid adaptation, handwriting prediction, and box-free OLCR. Hybrid adaptation is an integration of adaptive classification (which is also a new feature) and adaptive context processing that realizes a higher recognition performance than these two methods on their own. Handwriting prediction almost doubles the text-input efficiency compared to common OLCR methods. It achieves this by combining handwriting recognition and input string prediction. Box-free OLCR brings a free, natural input style to the OLCR interface. As a result, in one experiment, our new OLCR technology achieved a tremendously higher recognition accuracy of 94.6% for Japanese text on

PDAs compared to other OLCR software, which had recognition accuracies of about 82 to 88%. In addition, the test subjects in this experiment said they preferred using our software. These results suggest that Fujitsu's OLCR technology is superior to the other software we tested.

The new features of Fujitsu's OLCR have been adopted by a Japanese language input software called Japanist 2003 and a handwriting input software called Japanist for Pocket PC, which works on Pocket PCs. In addition, we are developing a new handwriting software prototype that makes it possible to freely write character strings on PDAs with a small display.

We are making continuous efforts to improve the recognition accuracy and usability of handwriting interfaces.

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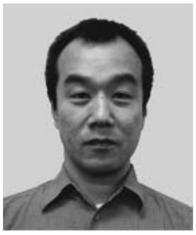

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