“Body Coupled FingeRing”: Wireless Wearable Keyboard

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ABSTRACT

A really wearable input device “FingeRing” is developed for coming wearable PDAs. By attaching ring shaped sensors on each finger, many commands or characters can be input by finger-tip typing action. “FingeRing” can be used on any typing surface such as a knee or desk, so quick operation is realized in any situation while standing or walking. To improve wearability, a very small, ultra low power wireless transmitter is developed that uses the human body as part of an electric circuit. “Direct Coupling” method enables stable communication even when body contacts any grounded surface. A new symbol coding method that combines order and chord typing is also proposed, and useful typing patterns are chosen by typing speed evaluations. Expert users of musical keyboards can input 52 different symbols at speeds of over 200 symbols per minute by using the combination of FingeRing and the new coding method.

Keywords: wearable computer, PDA, interface device, input device, keyboard, PAN, BodyNet, FingeRing

INTRODUCTION

The main reason for carrying a PDA is immediate access to information whenever desired. We want to carry information not a machine. Existing PDAs are much bigger and heavier than the information within them. However, PDAs become smaller and lighter given the progress in semiconductor technology. PDAs will be worn as accessories one of these days. The question is how to operate them.

Many concepts and prototypes of wearable computers have been proposed and partly developed. However, small interface devices suitable for wearing have not been well researched. Apple computer announced an image model of a wearable Macintosh[1]; a small wrist mounted trackball was used as its input device. The wearable computer project of MIT used a grip type chord keyboard[2], and some PDAs use miniaturized full or ten-digit keyboards. These interface devices depend on the physical size of the operative organ such as the human hand or finger. For instance, a keyboard whose key pitch is less than 14mm has lower input speed, higher fatigue levels and higher input error than the standard size keyboard[3]. Therefore, there is a trade-off between portability and usability. In other words, it is difficult to miniaturize ordinary interface devices without sacrificing their ease of operation. For the coming wearable PDAs, we think that specially designed interface devices that can be highly miniaturized are needed.

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Glove or fingerstall style virtual keyboards which detect bending or typing action of fingers by sensors mounted at joint or tip of fingers, have been proposed[4][5]. These systems seem suitable for wearable use because they do not require a key-top or key-pad. However, they cause trouble in daily life operation because they cover the finger-tip which has the highest tactile sensitivity or hand by sensor or glove. A virtual keyboard for a daily use wearable PDA should not cover the finger-tip or hand.

Considering these situations, we described an interface device which is suitable for wearable computers, and developed the FingeRing system[6][7], which is a “ring” shaped full-time wearable keyboard (**Figure 1**) . Users can input commands and characters by finger-tip typing actions on any support surface such as a knee or desk whenever desired. The small sensors do not cover finger-tips, so wearing such devices does not hinder our daily life.

FingeRing does not requires a particular space to be tapped by fingers such as a key-top or a key-pad, so usability does not worsen with miniaturization. However, the current FingeRing needs a direct electrical connection

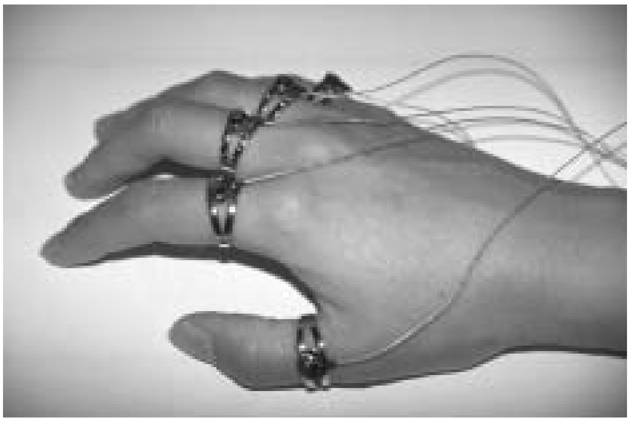

Figure 1: Sensor part of FingeRing (wired version).
Detecting finger-tip typing actions by accelerometer.

from the sensors on each finger to the symbol generator placed on a wrist. Even if the sensors and symbol generator are greatly miniaturized, the wire connection causes inconvenience in daily use. For example, the wires are frequently twisted and become tangled. Therefore, to realize truly wearable devices, we must establish wireless communication between the sensors and the symbol generator module. This paper compares several very short range, ultra low power wireless communication methods for their application to FingeRing. We choose the method called "Body Coupling" which uses the human body as an electric wire. We discuss the problems encountered in applying the body coupling method to FingeRing and propose "Direct Coupling" as a solution.

FingeRing is a kind of "chord" input keyboard, which makes symbols such as command or character through combinations of simultaneously typed fingers. Some chord keyboard systems have been proposed[8], but these systems tend to adopt useless (= hard to type) chord patterns to represent many symbols with one stroke typing actions. We propose a new coding method that combines of order and chord typing actions to increase the number of representable symbols without sacrificing input speed.

FINGERING

FingeRing is a prototype of a full-time wearable device for the input of commands and characters. A small accelerometer is worn on the base of each finger to detect the typing shocks generated by tapping the finger on any typing surface such as the thigh, knee or desk (called "finger-tip typing"). Commands and characters are generated from combinations of finger-tip typing actions. Each accelerometer is small and the finger-tip is not covered so they can be worn continuously in everyday life without trouble. In addition, no take-up action is needed for use, so immediate start of operation is possible.

Detection of finger-tip typing

Acceleration by finger-tip typing conveys from the finger tip to the sensor which is mounted on the base of typed finger. The acceleration is called "Self typing". However, the acceleration of the other fingers is also received by the same sensor; this is a type of cross-talk. Therefore, it is necessary to isolate the intended typing acceleration from the others. **Figure 2** shows the frequency distribution of accelerometer output. Five subjects (154cm to 190cm in height) mounted accelerometers on the bases of their five fingers, and made finger-tip typing actions on a desk (reflects "Hard" typing surface) and on a thigh (reflects "Soft" surface). **Figure 2** indicates that the self-typing and cross-talk signals have an amplitude difference of about 10 to 15 dB in the frequency area around 90Hz. Thus, a sharply carved Band Pass Filter (BPF), which passes only frequencies around 90Hz, can be used to eliminate the cross-talk regardless of typing surface stiffness. The example of BPF (24dB/Oct) setting is also shown in **Figure 2**. To be accurate, the filter property should different for each finger, but a simple resonance type BPF which has center frequency of 90Hz and Q[1] = 6 can be applied to all fingers.

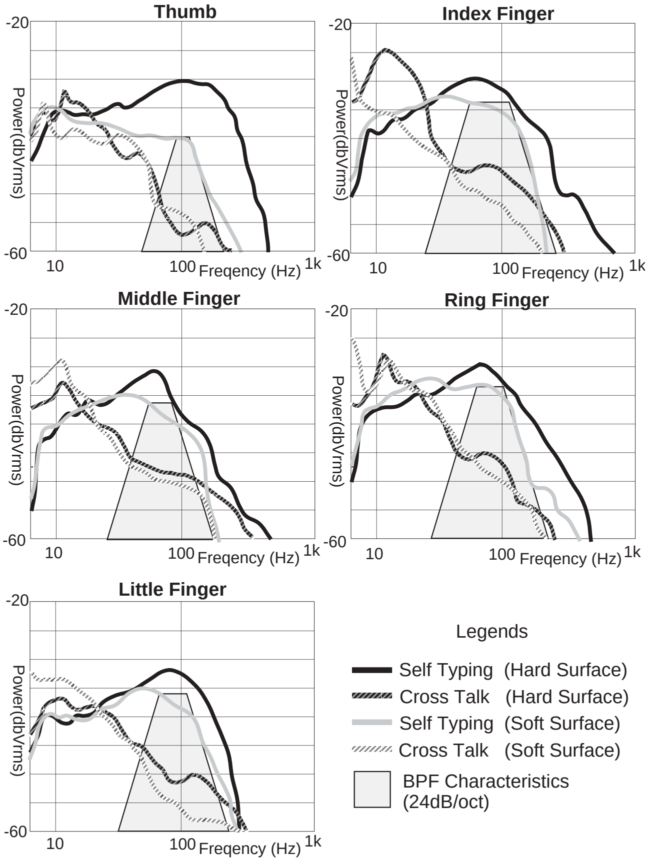

Figure 2: Frequency spectrum of typing acceleration. Self-typing and cross-talk signal can be separated by difference in frequency distribution.

WIRELESS LINK

FingeRing can be highly miniaturized without sacrificing ease of operation. However, the current FingeRing needs a wired connection from each sensor to the symbol generator. These connections cause many troubles such as catching on objects, even if the wires are extremely short. Therefore, to realize a truly wearable device, we must establish wireless communication between the sensors and symbol generator module.

Wireless link methods

The wireless communication method for FingeRing must have the following characteristics.

- Easy miniaturization:
  Miniature transmitters (TX) are especially required. (target size of TX: less than 10mmϕ, less than 10mm high, few grams in weight)
- Low power consumption:
  One day operation with one time charging is desired. (target of TX: less than 1mA in current consumption, 3 to 5 volt power supply)
  No battery operation is best if possible.

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[1] Quality factor: Sharpness of resonator

Table 1: Methods of wireless communication.
Body coupling is suitable for wireless link between ring and wrist.

method	miniaturization	power consumption	non line-of-sight	multiple link	remarks
optical	B	B	D	A	line-of-sight only
radiowave	C	D	B	A	much power needed
sound(electric)	C	C	A	C	
sound(mechanical)	A	A	A	C	no electric power
magnetic field	C	C	B	B	does not utilize human body
body coupling	A	B	A	A	use body conductivity

[A]:Better / [B]:Good / [C]:Bad / [D]:Worse

- Non line-of-sight communication:
  Line-of-sight communication cannot be established between the transmitter (TX) mounted on the base of finger and the receiver (RX) mounted on the wrist when the hand is bent inward.
- Multi channel communication:
  It is necessary to separate the signals of each finger (typically five).

The characteristics of several communication methods are shown in **Table 1**. Optical communication realizes high-speed links, but requires a line-of-sight condition. Moreover, at least 1mA of current is needed to drive an LED. Radiowaves (air wave) allow non line-of-sight communication when the distance is very short, but the electric power consumption is high. Sound wave are suitable for non line-of-sight communication, but electric-to-sound transducers are hard to miniaturize, and the efficiency of energy conversion is poor. Nevertheless, non-electric power operation can be realized if a mechanical sound generator is constructed by micro machining technology. BPFs for the detection of self-typing will also be unnecessary if the mechanical sound generator has frequency selectivity. Communication by magnetic coupling is feasible with less electric power consumption when the communication distance is short such as between finger and wrist. However, coils of many turns are needed which can not be easily miniaturized. Moreover, the permeability of the human body is almost the same as that of the atmosphere and the effect of magnetic flux concentration can not be anticipated.

Fortunately, the human body has good conductivity. Therefore, by using human body as a signal route (= electric wire), seemingly wireless communication can be realized. For these reasons, we selected the communication method called "Body Coupling" which uses the human body as an electric wire.

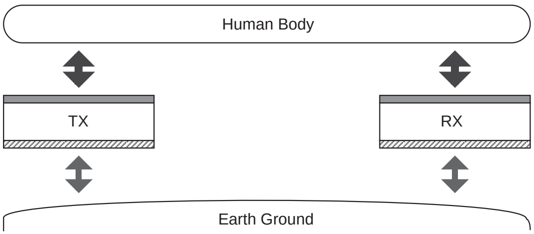
Body coupling

The human body has some electrical conductivity at comparatively high frequencies. Body coupling is a communication method that transmits electric signals via the human body. It is dangerous to pass excessive current through the human body, and limits have been set by many countries. For example, the current limitation on the skin surface as specified in Japan (JIS T1001-1992) is 10μA at DC-1KHz, 100μA at 10kHz, 1mA at 100kHz and 10mA at over 1MHz. As the signal frequency increases, the current limit is correspondingly increased. Thus, it is effective to use high frequency signals, over dozens of Khz, when transmitting electric signals through the human body. For example, current flow at the skin surface is a maximum of 160μA when a 100KHz, 50Vp-p sine wave signal is injected into the skin via 10pF capacitively coupled electrodes. In this case, flow current is 6 times smaller than the limit and there is no deleterious effect on the human body. In addition, the metallic parts of the electrodes do not contact the human body directly.

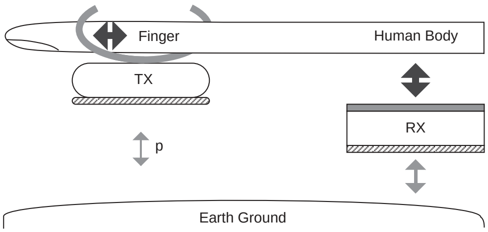
"Personal Area Networks (PAN)[9][10]" is another communication method that uses the human body as an electric circuit. TX and RX electrodes are placed near the human body to establish a data link by using spread spectrum (SS) modulation with carrier frequencies of 100kHz to 1MHz. The coupling model of PAN is shown in **Figure 3**-a. In a PAN system, TX and RX electrodes capacitively couple to the human body. It is necessary for establishment of a electric circuit to make an electrical loop. PAN uses the human body as one (signal) side of the loop, and "earth ground" as the other (return) side. In this case, circuit efficiency is greatly exhibited when the signal side electrode is placed near the human body and the return side is placed near the earth ground. The paper[9] states that a shoe insert is the best location for the TX and RX electrodes. The paper also described examples of PAN devices such as a wrist watch and eye glasses. However, we think that extremely small PAN devices cannot work properly.

Figure 3-b shows the coupling model of a small (ring) TX mounted on the base of the finger for FingeRing application. In this case, the coupling between signal side electrode and human body is strong enough, but the return side electrode is so small and the distance from the earth ground is so far that coupling ('p' in the figure) is weak and the effective communication distance becomes too short. Moreover, when the finger is typed on the human body such as the knee or the thigh, the TX is surrounded by the body which is used for signal side path, and the coupling between the return side electrode and the earth ground becomes too weak.

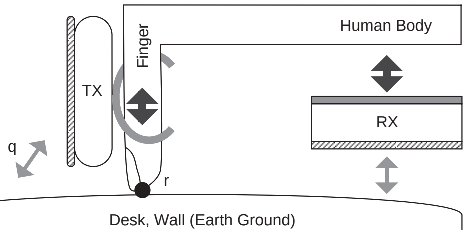
Another problem occurs if the body contacts a grounded surface(**Figure 3**-c). The paper[9] states that the sensitivity of the RX is reduced by about 20dB when the body (signal side) contacts the earth ground (return side). In FingeRing, finger-tip typing may be taken on desk-top or wall surfaces, which can be regarded as the earth ground in many cases. Thus, the data link from TX to RX is cut



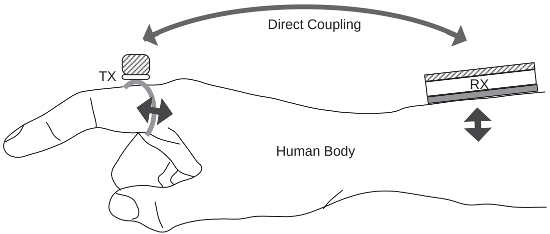
(a) Coupling model of PAN



(b) Coupling model of PAN (Small size TX)



(c) Coupling model of PAN (Desk top typing)



(d) Direct Coupling between ring-TX and wrist-RX

Figure 3: Coupling models.
(b)(c): PAN's coupling become weak when transmitter is small, or human body contacts the earth ground.
(d): Direct coupling can be work well, even if TX is small (ring) size and human body contacts a grounded surface.

when the finger tip contacts the desk or wall for typing. Therefore, it is hard to directly apply the PAN method to FingeRing.

Direct coupling

In FingeRing, the communication distance is about 15cm, finger base to wrist. Thus, the TX and RX return side electrodes can be directly coupled via air, without using the earth ground (**Figure 3**-d). In this case, couplings between the earth ground and both TX and RX return side electrodes are weaker than the direct coupling between both return side electrodes. Therefore, TX - RX coupling is not influenced by the nearness of the earth ground, and problems related with the earth ground can be solved; for example, finger-tip typing on the knee or the thigh (the earth ground is so far), and that on the desk or the wall (the earth ground contacts the body). In this "Direct Coupling" method, sensitivity is still reduced when the human body contacts or comes very near to the TX or RX return side electrode. However, this problem can be solved by placing the return side electrode of TX on the back of the finger, and that of RX on the upper side of wrist. Consequently, the human body does not contact either return side electrode in ordinary use. Thus, we chose the direct coupling method to realize a wireless FingeRing system.

WIRELESS FINGERING

Modulation

Ring style TX of FingeRing must meet the following requirements.

- Extra low power consumption
- Multiple channel communication

Frequency modulation (FM) offers several good advantages. It requires few parts (= low power consumption) and can easily support multiple communication channels. In the wireless FingeRing, the output of each accelerometer is directly transmitted as an analog FM signal, so the TX circuit is simple. Carrier frequencies of the five fingers are set as 50k, 58k, 67k, 78k and 91kHz to avoid interference from higher harmonics.

TX amplifier

The output voltage of the FM modulator swings at 3 to 5 volts, and amplification is needed to enhance the communication distance. Wireless FingeRing uses a combination of a choke coil and an LC resonator to boost output voltage. By using this combination, output voltage is easily boosted with low current consumption; for example, 42 Vp-p output signal is generated in 180μA of current consumption.

Electrode

The ring shaped TX uses its "ring" part as the signal side electrode, and the housing of the TX is used as the return side electrode to maximize electrode area. Each electrode is molded within an insulator, and the metallic part of the electrode does not directly contact the human body. An electric double layer capacitor is used as the power source, as it has the good characteristics of fast and easy charging. A block diagram of the TX is shown in **Figure 4**. The RX electrode is mounted on the wrist. The signal electrode is placed on the skin side of the wrist band, and the return electrode is placed on the outer side of the wrist band near the back of the hand. In order to improve RX sensitivity, it is necessary to keep the return

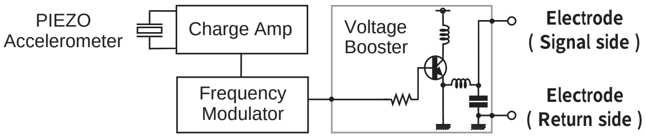


Figure 4: Block diagram of FingeRing (TX).
Frequency modurated sensor signal is boosted by choke coil and LC resonator.

Figure 5: Wireless FingeRing (prototype).
Size of TX will be reduced by the use of specially manufactured IC chip.

side electrode far from the human body.

Performance
Power consumption of the prototype TX, which includes sensor driver, is 1.75mW (5V, 0.35mA) per channel, and operation time with electric double layer capacitor (5V, 0.22F) is about 30 minutes per charge (takes 2 minutes). Maximum communication distance is 20cm for the combination of ring style TX and disc (3cmϕ) shaped RX electrode. In addition, the attenuation is 3.7dB when the hand is placed on the body, and 4.2dB when the hand contacts any grounded surface, in comparison with the reference condition when the hand is stretched out in the air. Communication can be stably established in all conditions, and the effectivity of direct coupling method has been confirmed. The prototype of wireless FingeRing (TX and the electrode part of RX) is shown in **Figure 5**. Size of the prototype TX is 20mm of diameter and 20mm of height, because it uses conventional DIP package ICs. With the use of specially manufactured ICs, TX will be able to miniaturized toward the ideal size (less than 10mm in diameter, 10mm in height).

PROBLEMS

TX battery charging

The prototype TX is charged by direct connection to the battery. However, TX and RX housings must be fully molded and the charging process must be a non-contact type for waterproofing. Electromagnetic induction can supply comparatively large power, but it does not suit miniaturization because it is coupled by AC and requires a large capacitor to reduce ripples in the AC to DC converting stage[2]. Solar batteries can generate DC power with no additional parts. However, existing single crystal solar cell about 10mmϕ generate only 10μW indoors (500lux), and charging under indoor operation is not realistic.

The prototype TX continuously transmits a carrier signal and wastes electric power needlessly. It would be better if the TX transmitted only during typing, but this method has problems; the boot-up stage of oscillation is unstable and the detection of typing is somewhat delayed.

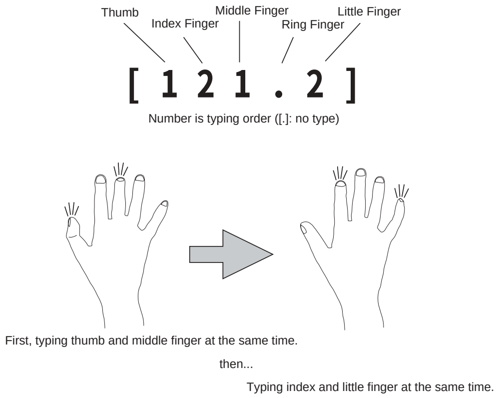


Figure 6: Notation of orderly typing chord input method
Corresponding finger is typed as the order of chord number (same numbered finger is typed simultaneously).

Channel multiplexing

In order to operate plural FingeRing systems simultaneously, it is needed to increase number of communication channels, but expanding the carrier range causes interference from higher harmonics and beat signals from multiple carriers. In FingeRing, the local TXs are close to the local RX, while other TXs are farther away. In this case, interference from other TXs which uses same carrier frequency can be ignored by the masking effect of frequency modulation ("The law of the jungle") when the local TX is active. Therefore, many FingeRing systems which uses same frequency bands can operate simultaneously. However, interference appears when the local TX is quiescent. This interference can be avoided without excessively increasing carrier range by assigning a unique ID to a group of TXs and RX for one user. The ID number transmitted with the sensor signal is compared in the RX, and only the signal with valid ID number is accepted. A method for programming and transmitting IDs with little additional circuit is needed.

CHORDING METHOD

Orderly typing chord input

FingeRing is a kind of "chord" input keyboard, which represent symbols such as commands or characters by combinations of simultaneously typed fingers. Many chord keyboards represent symbols by one-stroke typing actions. Therefore, useless (= hard to type) chord patterns are sometimes used to represent many kind of symbols with few fingers (typically five). FingeRing combines chord input with order input, which means that the typing actions that has slight time lag each other, for represent many kind of symbols without using hard typing actions. Notation of this method is shown in **Figure 6** and example of chord sequence determination is also shown in **Figure 7**. An outline of the combination input method (named "orderly typing chord input") is given below.

- Define one-stroke chord as a combination of typed fingers where the period between the actions is less

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[2] The electric double layer capacitor can not absorb ripples.

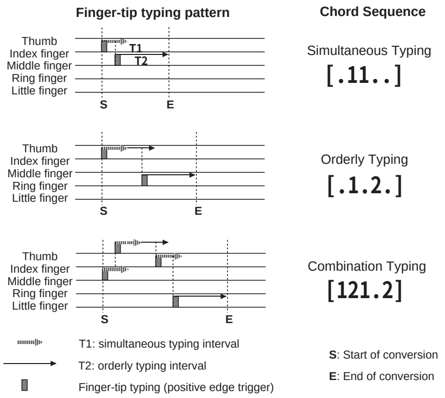

Figure 7: Example of chord sequence determination.
Simultaneous and orderly typing is separated by two time constants T1 and T2.

than a pre-determined interval time named "simultaneous typing interval: T1".

- Define one symbol as a sequence of chords where the period between the actions is less than a predetermined interval time named "orderly typing interval: T2".
- The consecutive typing of same finger is not contained in one chord sequence.
- Only the chord sequences that can be input quickly are selected and used.

In this method, the number of representable symbols can be increased by increasing the number of maximum strokes. But excessive stroke number deteriorates input speed, and some combination of diffrent strokes disturb the input rhythm. Therefore, FingeRing uses two-stroke chord sequences which can be input as quickly as one-stroke chord patterns. In addition, chord sequences of more than three strokes can be used for key-macros, special commands and passwords.

Typing speed evaluation

Experiments were conducted to select the usable chord sequences by using a wired version of FingeRing. Subjects typed displayed chord sequences as quickly as possible. One chord sequence was displayed in each trial. In order to remove reading and understanding time of each displayed chord sequence, and to maintain a constant finger placement at the start of each trial, the time between start chord ([11111]) typed by subject and the end of displayed chord sequence, was measured with a resolution of 1msec. 212 chord sequences were tested to each subject; the set contained all the 31 patterns that can be represented by one-stroke combinations, and all the 181 patterns that can be represented by two-stroke combinations where the same finger is not used consecutively. The chord sequences were displayed at random, and the trials iterated until at least one correct typing sequence was obtained for each of the 212 chord sequences. Data was collected only for trials resulting in correct typing, which means the order of the finger-tip typing agreed with the displayed chord sequence.

The finger-tip typing surface used in the experiment was a desk covered with a thin urethane sheet (5mm); this stiffness is intermediate between "Hard" and "Soft" surface as previously described. Total number of subjects was 10 and all had experience in QWERTY style computer keyboard operation. As a result of a brief experiment, a significant difference was observed between subjects who have experience in playing musical keyboards (piano group) and those who have no experience (non-piano group). Therefore, collected data was split into two groups; piano and non-piano group.

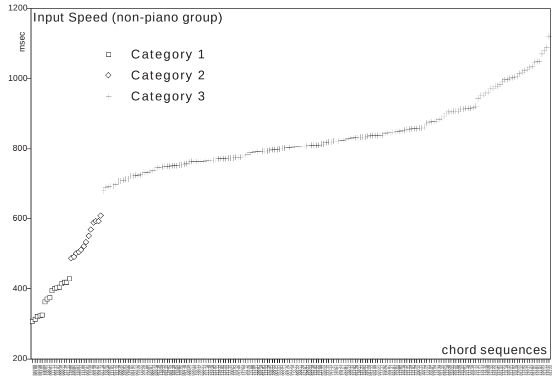

Figure 8: Distribution of typing speed (non-piano group)
Chord sequences can be divided into 3 categories.

Table 2: Chord sequences and average input time. (non-piano group)
The effectiveness of orderly typing is less for the non-piano group.

chord sequence	average input time(msec)	chord sequence	average input time(msec)
Category 1		Category 2	
.1...	306.3	**1...2**	487.0
..1..	313.0	.1..1	491.0
.1.1.	321.7	11..1	500.3
.11..	322.3	.1.11	504.7
1....	324.3	111..	509.7
1...1	363.3	11.11	520.7
1..11	371.3	..1.1	532.7
....1	374.3	11.1.	550.3
11111	394.0	1.1..	568.3
..111	400.7	..11.	588.7
1.1.1	402.7	**..1.2**	591.3
...1.	404.7	1.111	592.3
...11	414.7	.111.	607.0
1111.	418.0	Category 3	
.1111	418.3	1..1.	689.3
11...	427.7	111.1	693.0
		1.11.	750.7
		.11.1	792.3

Bold font indicates orderly typing.

Figure 8 shows the average input time for each chord sequence for the non-piano group. It is seen from the slope of the curve that the chord sequence set can be divided into 3 categories. The categories are numbered 1, 2, and 3 starting with the shorter input time. Input time of a chord sequence is considered to reflect the difficulty of typing that sequence. In other words, category 1 offers easiest typing. **Table 2** shows the chord sequences and average input times for categories 1 and 2. One-stroke chord patterns belonging to category 3 are also shown in **Table 2**. In selecting the chord sequences to be used, category 1 is used first. If there are still more symbols are needed, category 2 chord sequences are assigned. Chord

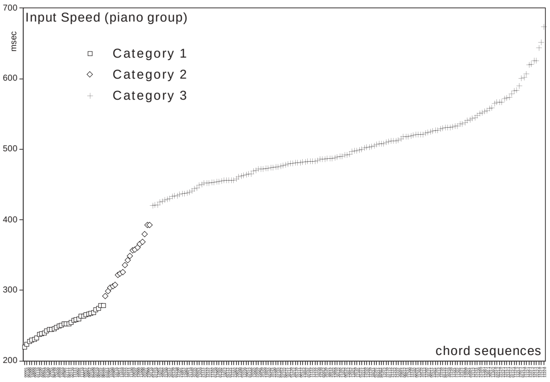

Figure 9: Distribution of typing speed (piano group).
Input speed is collectively faster than non-piano group.

Table 3: Chord sequences and average input time. (piano group)
Many two stroke chord sequences can be input as a same time of one stroke chord.

chord sequence	average input time(msec)	chord sequence	average input time(msec)
Category 1		Category 2	
....1	220.0	.1.11	291.2
..1..	223.8	**.2..1**	298.0
.1...	228.2	**1.2..**	303.6
1....	229.4	**.1..2**	305.0
...1.	231.2	1.11.	307.4
.111.	232.4	1..11	321.0
1.1..	237.4	11.1.	323.6
...21	238.6	**1.222**	325.4
.1.1.	239.4	**12222**	335.8
.12..	242.6	1.111	342.0
1...1	244.2	111..	348.8
.11..	244.6	**2..1.**	356.2
..11.	245.2	**1.2.1**	356.8
1..2.	247.6	**12...**	360.6
.1.2.	249.8	11...	364.8
1..1.	250.2	**2.1..**	367.8
.1..1	252.4	**2..21**	379.6
.1111	252.4	**21...**	392.0
..111	253.0	**2.11.**	392.2
..12.	255.0	Category 3	
11111	257.2	.11.1	420.0
1...2	258.4	11..1	421.2
1.1.1	260.0	11.11	437.0
1111.	263.2	111.1	454.8
...11	264.0		
2...1	266.0		
...12	266.8		
.21..	267.4		
.2.1.	268.2		
..21.	272.8		
..2.1	274.8		
..1.1	278.2		
..1.2	278.4		

Bold font indicates orderly typing.

sequences of category 3 should be avoided even if one-stroke typing is used. In the non-piano group, only 2 orderly typing sequences appear in category 2 (indicated by bold-face characters).

Figure 9 shows the average input time of the piano group for each chord sequence. The chord sequences can be divided into 3 categories, as in the non-piano group. **Table 3** shows the chord sequences in category 1 and 2, together with the corresponding average input time. The one-stroke chord patterns belonging to category 3 are also shown in **Table 3**. It is seen from the table that a large number of orderly typing sequences are included in categories 1 and 2 (indicated by bold-face characters).

Table 4: Number of representable symbols and average input time.
Proposed chord input method is suitable for untrained (non-piano) user with command input operation, and for trained (piano) user with command + character input operation.

	Category 1		Category 1+2	
group	symbol (ex.)	input time (ms)	symbol (ex.)	input time (ms)
piano	33	251.3	52	283.9
(trained)	(alphabet)		(alphabet,number,etc.)	
non-piano	16	373.6	27	442.3
(untrained)	(command,number)		(alphabet)	

Efficiency of the coding method

The result of finger-tip typing experiment is shown below.

- Input speed of the piano group was about 1.5 times faster than that of the non-piano group.
- The effect of orderly typing is less for the subjects of non-piano group.
- The orderly typing chord input method was most effective for the piano-group. The number of representable symbols is doubled by the same input speed as that of the one stroke chord input method.

Table 4 shows the number of representable symbols and the average input time when the chord sequences of category 1 or both of category 1 and 2 are used, for non-piano and piano groups. It is thought that the proposed input method will be effective for trained user of chord keyboard, if the skill needed to operate a chord keyboard is equivalent that needed to operate a musical keyboard.

Separation of simultaneous and orderly typings

When orderly typing is used with simultaneous typing, it is necessary to separate both typing styles by using the interval between typing actions. Based on the timing data of the finger-tip typing of each finger obtained by the above experiment, two time constants (T1: simultaneous typing interval, and T2: orderly typing interval), were estimated. The data was collected from the piano group because orderly typing was efficient in this group.

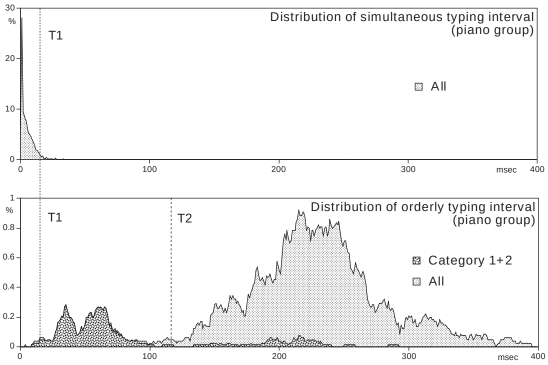

Figure 10: Distribution of simultaneous and orderly typing intervals (piano group).
1) Simultaneous and orderly typing can be separated properly by setting T1 as 15msec.
2) Chord sequences of category 1 and 2 have shorter orderly typing intervals.

The distribution of time intervals of simultaneous typing, and that of orderly typing are shown in **Figure 10**. The total number of collected intervals was 1705 for simultaneous typing and 910 for orderly typing. In **Figure 10**, the distribution of the orderly typing interval for the chord sequence belonging to category 1 and 2 is shown as heavily hatched plot. This figure shows that simultaneous and orderly typing can be separated, by setting T1 as 15msec. It is also seen that quick input can be enabled by setting T2 as 120msec, when only chord sequences belonging to category 1 and 2 are used. Moreover, the distribution of the simultaneous typing interval of the non-piano group was similarly collected; T1 of this group was estimated to be 20msec.

Symbol table assignment

This experiment evaluated the combinations of finger actions that can be typed quickly, for collecting fundamental data for symbol table assignment. However, effective assignment of symbol table such as commands or characters is strongly depended on each application. Moreover, it is necessary to modify the symbol table for each user to suit the individual's characteristics, for example, one finger may be rather stiff. Therefore, the symbol table should be assigned not for general purpose use but for application and user specific. Evaluating the learning curve of this method is a remaining problem.

From the view-point of the ease of training and ease in recalling forgotten patterns, it is necessary to assign "patterns that can easily be recalled", even if the input speed deteriorates to some extent. In orderly typing, for example, some chord sequence pairs are "reverse order" and assigning them to mirror reversed symbols seems most efficient, for example parenthsis '(' and ')'. Combinations of symmetrical chord sequence pairs which can be typed easily, are shown in **Table 5**.

In the above experiments the error rate was not collected, because separating human and machine (FingeRing) error is difficult. Moreover, human input error tend to occur between specific chord sequences, thus "fault tolerant" symbol table might need to be considered. For example, if chord sequence 'A' is often mis-typed as sequence 'B', critical commands should not assigned to chord sequence 'A' and 'B', or the same command assigned to both chord sequences.

CONCLUSION

This paper has described a wireless communication method that links the sensors and the symbol generator module of FingeRing, a command and character input device developed for wearable PDAs. We showed that body coupling, which uses the human body as an electric conductor, is effective for very short range, ultra low power communication. Moreover, the direct coupling method which does not contains the earth ground in its transmission route is also effective even when the return side electrode of TX is very small. The direct coupling method also offers stable communication when the human body contacts a grounded surface. A prototype TX was introduced that has a power consumption of 1.75mW and about 30 minute operating time per 2 minute charge; the maximum communication distance is 20cm.

Table 5: Symmetrical chord sequence pairs.
Symmetrical chord sequences are suitable for symmetirical symbols such as '(' and ')'.

chord sequence	symmetorical sequence
1.22.	2.11.
1..22	2..11
1.222	2.111
12222	21111
12.2.	21.1.
1.2.2	2.1.1
12..2	21..1
1222.	2111.
.121.	.212.
.122.	.211.

This paper also described a symbol coding method for FingeRing, named the orderly typing chord input. For the untrained user (with no experience in musical keyboards), the effectiveness of the orderly typing is less. Up to 27 symbols can be typed easily using one hand, and the average input speed is approximately 130 symbols/min. On the other hand, the proposed method is effective for the trained user (with experience in musical keyboards). Up to 52 symbols can be typed easily, and the average input speed is approximately 210 symbols/min. Consequently, when this method is used for the input interface, the untrained user should concentrate on cursor motion and simple commands. The trained user can quickly input not only various commands but also the alphanumeric characters.

We are testing menu structures, suitable assignment of symbol table, and a feedback method by testing a prototype "Walking PDA" which uses FingeRing as the input device and a text-to-speech synthesizer as the feedback device. Application to musical use such as piano and drums is also being developed now. We are planning to enhance the operation time, communication distance, channel number, and non-contact charging method to realize a "full-time" wearable FingeRing.

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