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Painting in the air with Wii Remote

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ABSTRACT

The Wii, which is a home video game console released by Nintendo, has rapidly become the world's most popular console since its release in November 2006. A distinguishing feature of the Wii is its innovative motion-sensitive controller, the Wii Remote, which could be used as a hand-held pointing device and that has brought many people to gaming for the first time. The popularity of Wii and the innovative design of Wii Remote provide us the motivation to develop a novel air painter system which includes basic painting functions, free sketching, and Chinese, English and Japanese recognition. Vibration and noise effect often influence the recognition of the system, so several fault tolerance mechanisms are proposed in this paper to reduce these effects. Moreover, a unifying character and free sketch recognition scheme, which is based on the stroke code sequences, is proposed to process the recognition. One of the advantages of this approach is that the same mechanism could be applied to the whole system and it could incorporate the fault tolerance mechanisms proposed in this paper.

1. Introduction

The Wii, which is a home video game console released by Nintendo, has rapidly become the world's most popular console since its release in November 2006. In the console business, the Wii leads the generation over the other console generation in worldwide sales, selling over 40 million units worldwide (Nintendo, 2009). A distinguishing feature of the Wii is its innovative motion-sensitive controller, the Wii Remote, which could be used as a hand-held pointing device and that has brought many people to gaming for the first time. In addition, Wii Remote consists of bluetooth technology and a single IR (infra-red) camera sensor. Bluetooth connectivity could make Wii Remote become a PC-compatible input device and make it possible to integrate the computation power of PC. The IR camera sensor provides the possibilities to develop interactive applications that could benefit from the characteristics of remote control. The popularity of Wii may make software applications which are developed for it readily usable by millions of individuals around the world.

Lee (2008) described the technology inside the Wii Remote. He has developed several Wii Remote projects ranging from multi-object tracking to spatial augmented reality. One of the innovative ideas behind the Wii Remote is that it has motion sensors inside it, meaning that simply waving the controller in the air is a means of input in itself. Besides, the Wii Remote also features force feedback, meaning events in the game can cause it to rumble for a more impressive feeling. Essentially, a basic goal of human–computer interaction is to improve the interactions between users and computers by making computers more usable and receptive to the user's needs. The Wii Remote's rich level of input and output combined with the ease of PC connectivity have made it an innovative platform for designing interactive applications. The popularity of Wii and the innovative design of Wii Remote provide us the motivation to develop a novel air painter system with handwriting recognition.

In this paper, a unifying character and free sketch recognition scheme, which is based on the stroke code sequences, is proposed to process the recognition. One of the advantages of this approach is that the same mechanism could be applied to character recognition and free sketch recognition. The handwriting recognition includes Chinese, English and Japanese. The users could use the Wii Remote as an input device and wave the controller in the air to manipulate the system. Practically, when the users hold the Wii Remote to write a character in the air, many unintentional vibrations may produce a lot of noisy information, which will affect the performance of the system. Furthermore, the system often needs to recover the information when trajectory information is missing. We proposed several fault tolerance mechanisms to reduce the effect of noise and vibration. The trajectory information will be transmitted to the gateway system and these fault tolerance mechanisms will be applied to the trajectory information to get more correct information.

In free sketch recognition, the system provides three shape recognitions including triangle, rectangle and circle. The features adopted in the system include the number of strokes and right angles. These two features could be identified easily based on free sketch stroke code classification model proposed in this paper. In

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addition to free sketch recognition, the air painter system provides basic painting functions such as font, color, object movement, etc. We have recently used Internet video to demonstrate our system and the video URL is http://www.youtube.com/watch?v=xQC6ZyXhfik.

2. Related work

2.1. Elements of Wii Remote

As shown in Fig. 1, Wii Remote integrates an IR camera and accelerometer to sense its position in 3D space when pointed at the IR sensor bar. The camera chip features an integrated multi-object tracking (MOT) engine, which provides high-resolution, high-speed tracking of up to four simultaneous IR light sources. Wii Remote has the capability to sense motion of the remote by a three-axis linear accelerometer. This allows for a whole new way for gamers to interact with game consoles. A sensor bar as shown in Fig. 2 allows the Wii Remote to determine where it is pointing to. Moreover, Wii Remote is equipped with bluetooth technology and the connection runs over a wireless bluetooth connection. The movement information of Wii Remote could be transferred to PC for further process. In other words, bluetooth connectivity could make Wii Remote become a PC-compatible input device and make it possible to integrate the computation power of PC with Wii Remote.

2.2. Handwriting recognition

In handwriting recognition, handwriting data is converted to digital form either by scanning the writing on paper or by writing with a special pen on an electronic surface such as a digitizer combined with a liquid crystal display. These two approaches are distinguished as off-line and on-line handwriting, respectively. In the on-line case with electronic surface, the sequence of strokes made by the writer could be obtained, so the two-dimensional coordinates of successive points could be regarded as a function of time. In recent years, HMM (Hidden Markov Model) has been successfully applied to European and American on-line character recognition (Hu, Brown, & Turin, 1996; Kundu et al., 1988; Marti & Bunke, 2001; Makhoul, Starner, Schwartz, & Chou, 1994; Nag, Wong, & Fallside, 1986; Plamondon & Srihari, 2000; Starner, Makhoul, Schwartz, & Chou, 1994).

Besides HMM approach, Hoque, Sirlantzis, and Fairhurst (2003) proposed a novel approach to classify handwritten characters based on directional decomposition of the corresponding chain-code representation. The technique basically relies on stroke

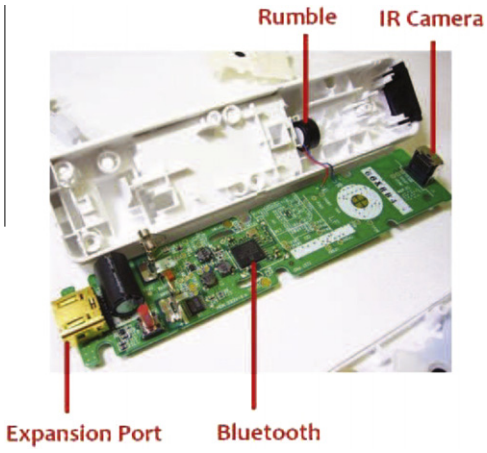

Fig. 1. Wii Remote controller.

Fig. 2. Wii sensor bar.

information as well as the direction of every stroke. In brief, the system integrates all stroke information to search the most plausible stroke data from the dictionary and yields the candidate words.

Nakai, Akira, Shimodaira, and Sagayama (2001) proposed to employ sub-stroke HMMs as minimum units to constitute Japanese Kanji characters and utilizes the direction of pen motion. As shown in Fig. 3, Nakai et al. analyze and classify Chinese words into 24 kinds of strokes, and use HMM to transform the most impossible strokes into the most possible ones to find the most plausible words. One advantage of sub-stroke HMM is that any character can be recognized, if its definition is added to the dictionary, without having it in the training data.

2.3. Free sketch recognition

Sketch recognition techniques have been applied to a variety of domains, including computer-aided design systems, painter, gestural interfaces, etc. A lot of handset equipments, such as PDA and cell phones, equip with sketch functionalities to provide a convenient interface for data input. The advantage of free-sketch systems is that they allow users to sketch in a non-constrained manner. The drawback of these systems is that recognition accuracy is modest, unless tuned for a specific domain (Hammond et al., 2008).

In general, sketch recognition includes gesture-based techniques and free-sketch recognition techniques. One of the characteristics of gesture-based techniques, such as those used by the Palm Pilot's Graffiti, is that the users need to learn a particular drawing style in order for shapes to be recognized. On the other hand, free-sketch recognition allows users to draw shapes as they would naturally, but most current techniques have low accuracies or require significant domain-level tweaking to make them usable (Hammond et al., 2008). It is important to reduce the noise and generate the best shape based on the drawing information and the domain knowledge, because the users may often draw imprecisely.

In general, we could use basic elements such as line, curve and corner to sketch complicated objects. For example, a triangle consists of three corners and three straight lines, and a circle consists of lots of curves. Sezgin, Stahovich, and Davis (2001) proposed to adopt curvature and speed information to detect corners. The intuition is simply that pen speed drops when going around a corner in the sketch and the local curvature is high. The curve detection is based on area of curvature. The ploy line approximation H_f generated in the process described above provides a natural foundation for detecting areas of curvature. Compare the Euclidean distance l_1 between each pair of consecutive vertices in H_f to the accumulated arc length l_2 between those vertices in the input S. The ratio l_2/l_1 is very close to 1 in the linear regions of S, and significantly higher than 1 in curved regions. Therefore, the ratio l_2/l_1 could be used to differentiate line and curve.

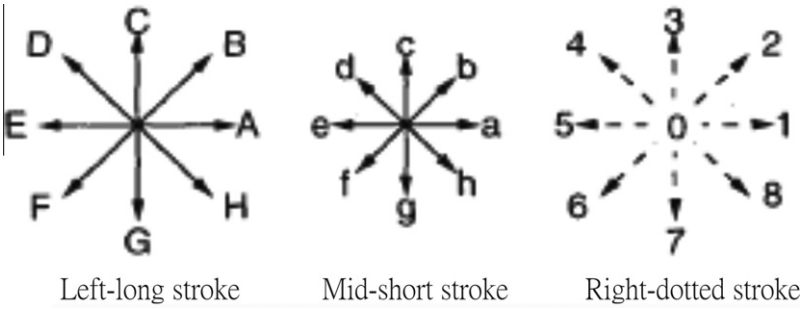

Fig. 3. Twenty-four kinds of strokes used by Nakai.

3. Unifying scheme for character recognition and free sketch recognition

The language of character recognition in this paper includes Chinese, English and Japanese. Unlike traditional on-line handwriting recognition system, the input device of the system is Wii Remote. Practically, many unintentional vibration may occur and produce noisy information, when the users hold the Wii Remote to paint in the air. Therefore, fault tolerance is necessary to reduce the effect of noisy information and the system needs to recover the information when trajectory information is missing.

Painting is the basic functionality of the system and free sketch recognition is integrated into the system. A unifying scheme for character recognition and free sketch recognition is proposed in this paper. Trajectory information arisen from waving the Wii Remote is used in the system to recognize the characters in different languages and will be encoded as corresponding code sequence. The following sections describe the trajectory classification for Chinese, Japanese and English.

3.1. Chinese recognition

According to our analysis, the strokes of Chinese can mainly be classified into five types:

- Type 1: Across strokes.
- Type 2: Vertical strokes.
- Type 3: Curve strokes.
- Type 4: Right-falling strokes.
- Type 5: Hybrid strokes.

In this paper, a circle is partitioned into different sections to represent the corresponding strokes. Fig. 4 shows the area of *Type 1*, *Type 2*, *Type 3* and *Type 4*, respectively. Furthermore, the strokes involved more than one type are grouped into *Type 5*.

3.2. Japanese recognition

Since Chinese symbols form an integral part of the Japanese language, the recognition described above is applicable both to Chinese and Kanji, which is the Chinese symbols in the Japanese language. The structure of Katakana is similar to Chinese words, but the number of stroke of Katakana is almost less than three. Therefore, we further decompose *Type 1* into *Type 1* and *Type 5* and that could improve the accuracy of recognition. Fig. 5 shows the strokes area for Japanese characters and *Type 6* represents the hybrid strokes.

3.3. English recognition

The biggest difference among English, Chinese and Japanese words is that English characters contain a lot of curves. For instance, the strokes of the English alphabet "O" is similar to a circle. Besides, a free sketch has no specific sequences and directions as well. In this paper, we proposed a simple approach to consider all the direction information. As shown in Fig. 6, a circle is divided into eight equal parts, and each part represents one direction of types. However, the curves in English may involve more than one direction, it may make the recognition more difficult. To simplify the stroke recognition, the stroke directions that are in the range of *Type 3* to *Type 5* will be simplified as *Type 3*; while the stroke directions that are in the range of *Type 6* to *Type 7* will be simplified as *Type 7*.

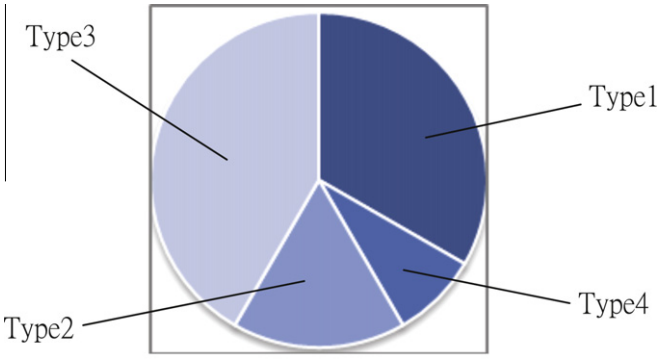

Fig. 4. Classification of Chinese stroke direction.

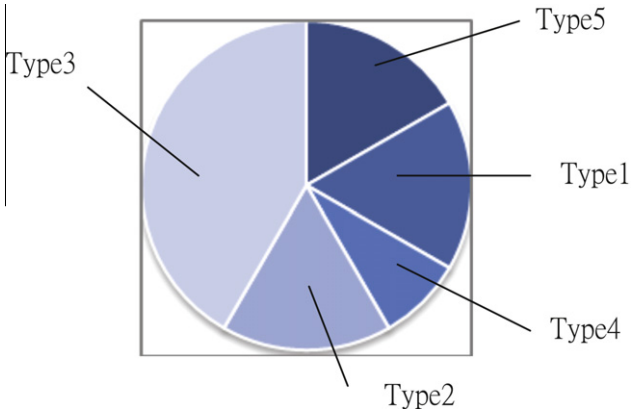

Fig. 5. Classification of Japanese trajectory direction.

3.4. Stroke code sequence database construction

Based on the stroke classification models mentioned above, the code sequences for Chinese, English and Japanese characters could be constructed as well. Fig. 7 shows an example of Chinese and Japanese encodings. In Chinese word recognition (it means wood and is pronounced as mu4), the first stroke is an across, which belongs

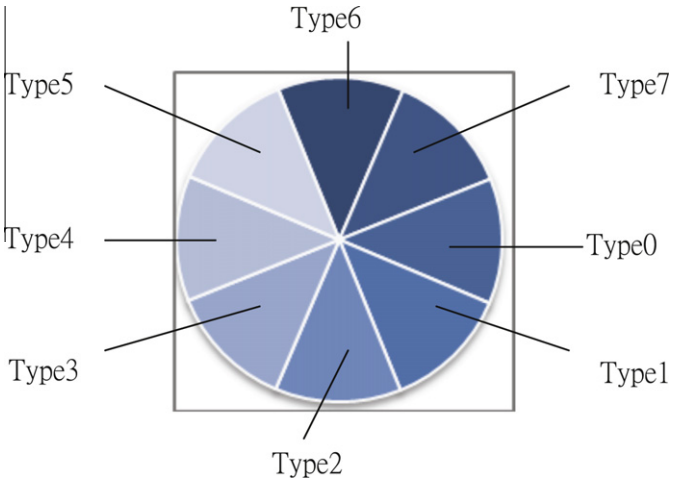

Fig. 6. Classification of English stroke direction.

to *Type 1*, so it will be encoded as "1". The second stroke is a vertical one, which will be encoded as "2". The third stroke is a left-falling stroke and the fourth one is a right-falling stroke, thus the corresponding codes are "3" and "4", respectively. Consequently, the encoding will be "1234".

Japanese encoding is similar to Chinese. Take the word appearing in Fig. 7 (pronounced as "ne") as an example, the first stroke is a right-falling stroke, which is encoded as "4". The second stroke belongs to *Type 1* and *Type 3*, so it is a hybrid stroke and it will be encoded as "6". The rest of the strokes belong to *Type 2* and *Type 4*. As a result, the encoding will be "4624".

However, Japanese characters consist of a lot of hybrid strokes, so false-positive rate will increase if the system only uses the *Type 6* to cover all hybrid strokes. Thus, *Type 6* is further classified into 4 other types according to ending strokes. If the ending stroke of hybrid stroke belongs to *Type 1*, it will be encoded as *Type 7*; if the ending stroke belongs to *Type 5*, it will be encoded as *Type 8*; if the ending stroke belongs to *Type 4*, it will be encoded as *Type 9*, and the rest will be encoded as *Type 6*.

English contains many curves and it will be difficult to get the eigenvalue if they are all regarded as hybrid strokes. For example, the curves in the alphabet "a" and "b" will be viewed as hybrid strokes. According to the curve direction in the English character, the stroke direction which is in the range of *Type 3* to *Type 5* is encoded as "3" and the stroke direction which is in the range of *Type 6* to *Type 7* is encoded as "7". As shown in Fig. 8, the encoding of *b* will be "2703", where the cures are encoding as "7" and "3".

4. System architecture

Fig. 9 shows the system architecture. When the Wii Remote faces the TV screen, the light emitting at both sides of the sensor bar will be captured by the infra-red camera of the Wii Remote. The Wii Remote's direction, distance and other situations in comparison with the TV screen can be estimated to some extent based on these two light points' positional relation and interval. The controller's gestures could be obtained from three-axial acceleration sensor. The area, where the user is pointing with the controller, could be obtained as well. As mentioned above, the Wii Remote is equipped with bluetooth technology, so these information could be sent to PC for further processing. System response will be projected to the TV screen and the users could see the results just like that the users are painting directly on the TV screen.

4.1. System processing flow

Fig. 10 shows the system flow. The air painter system in this paper adopts Wii Remote as the input device. When the user shakes the Wii Remote, the trajectory information will be sent to the system for analysis. Practically, when the user manipulates Wii Remote, the shakes of hands will give rise to noisy information which will influence tracking accuracy. Two schemes, noise filter and vibration filter, are proposed to reduce the influence of noise.

In handwriting recognition, three different language recognitions and free sketch recognition are provided by the system. The stroke direction identification model will identify the directions of stroke to generate corresponding code sequences. Additional fault tolerance mechanisms to increase the recognition rate are also proposed. The final part compares the classified stroke code sequences with the encoding sequences stored in the database, and the system could identify the best candidate characters from the comparison.

4.2. Input of Wii Remote

As described above, each Wii Remote equips an IR camera and could track IR light sources. When the users hold the controller and point to the screen where the sensor bar is located below the screen, the sensor bar will become the IR light sources. As shown in Fig. 11, the purple light-spots represent the locations of the infra-red. The *x*, *y*, and rotation values correspond to the controller's yaw, pitch, and roll, respectively. The distance is estimated using the known physical separation of the two IR groups and the camera's fixed field of view (Lee, 2008).

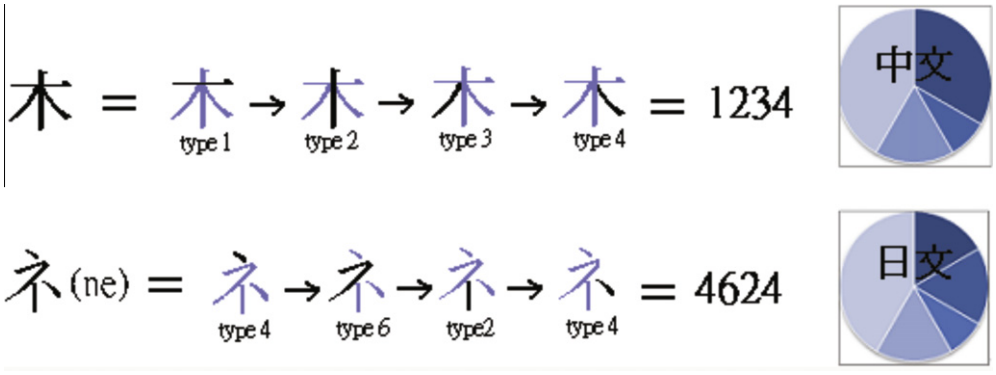

Fig. 7. Encoding of Chinese and Japanese.

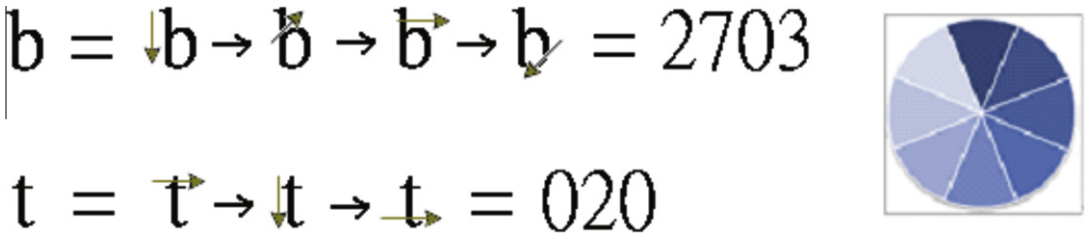

Fig. 8. Encoding of English.

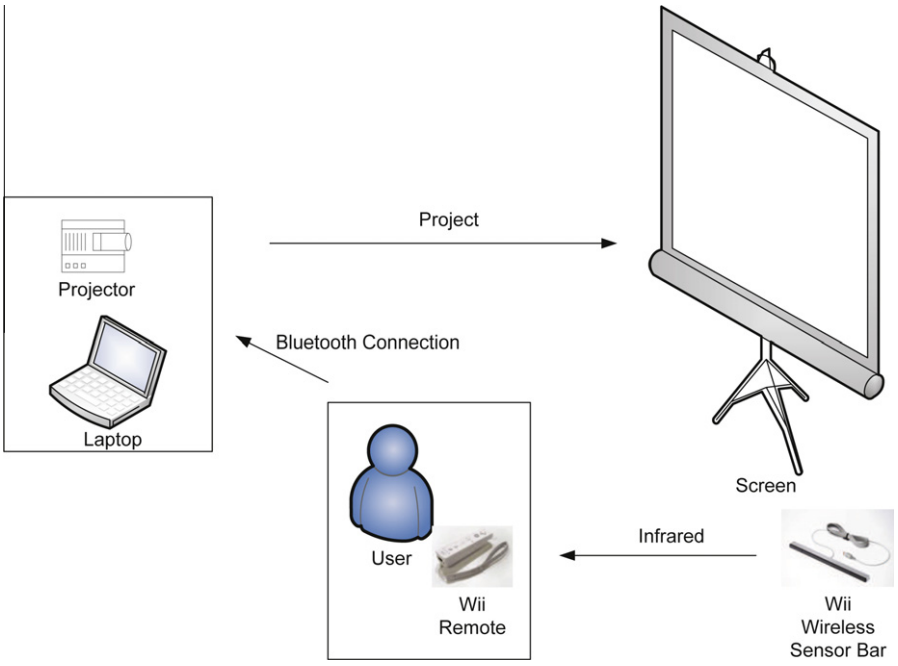

Fig. 9. System architecture.

The data received from bluetooth in the beginning will be regarded as the starting geocode of mouse cursor, and the displacement will be obtained if there is a continuous movement from Wii Remote. GlovePIE, which is used to process such a displacement and deal with geocodes of mouse cursor, is a program intended to emulate computer input hardware, such as joysticks and keyboards. With the help of GlovePIE, a Wii Remote could be turned into a mouse, joystick, or even script it for unique functions in games and software. Moreover, it also processes standardization according to the screen's dots per inch (DPI). Consequently, GlovePIE is adopted in this paper to act as the trajectory information gateway.

4.3. Trajectory processing

Practically, when our wrists are supported by a physical object, few vibration will happen. However, when the user holds the Wii Remote to paint in the air, there is no physical object to support the hands. As a consequence, unintentional vibration which brings noisy information to the system often takes place. Fig. 12 shows the trajectories feeding into the system when the user uses Wii Remote to write a Chinese word, which means "I". One can see that it is a challenging task to recognize it even for human being. In this paper, two approaches are proposed to reduce noises when manipulating the Wii Remote.

4.3.1. Noise filter

An unintentional vibration may cause noisy information to the system and make the system difficult to recognize correct stroke information. In general, the movement caused by unintentional vibration is tiny, so the system will drop the movement whose displacement is tiny to avoid misguidance. A threshold value k is defined, and the system will record the data only when the displacement is larger than k; otherwise, it will regard data as unintentional vibration. According to our experiments, this approach works well to filter out some noises.

4.3.2. Vibration filter

After noise filter process, noisy information may still exist in the system. Thus, the trajectory information obtained from the Wii Remote will still be a mix of noisy information and correct information. Practically, the direction of the Wii Remote will coincide with the direction of correct trajectory information. As a result, linear least squares technique is adopted in this paper to find out main trajectory direction.

In essential, the linear least squares fitting technique is the most commonly applied form of linear regression. It provides a solution to the problem of finding the best fitting straight line through a set of points. The goals of linear least squares are to extract predictions from the measurements and to reduce the effect of measurement errors. In other words, the least squares fitting tries to make as

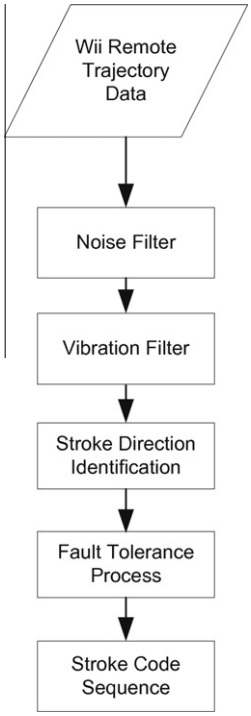

Fig. 10. System flow.

small as possible the sum of squares of errors. The least squares line uses a straight line as shown in Eq. (1) to approximate the given set of data, $(x_1,y_1),(x_2,y_2),\ldots,(x_n,y_n)$. Eq. (2) shows the least square error of the curve $f(x)$ with respect to the data (x_i,y_i)

$$f(a,b) = a + bx \tag{1}$$

$$R^2 = \sum_{i=1}^{n}[y_i - f(a,b)]^2 = \sum_{i=1}^{n}[y_i - (a + bx_i)]^2 \tag{2}$$

The unknown coefficients a and b in Eq. (1) could be determined by calculating the partial derivatives of R^2 as respect to a and b and setting them to zero. Eq. (3) shows the final result for unknown coefficients a and b

$$\begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} n & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i y_i \end{bmatrix} \tag{3}$$

Although the linear least squares fitting technique provides a solution to the problem of finding the best fitting straight line through a set of points, it needs some modifications to meet the requirement of the application in this paper. When the user holds the Wii Remote, the trajectory point information will continually be sent to the system. Essentially, outlying points can have a disproportionate effect on least square line, so new coming points that are far away from the original direction may affect the recognition. Fig. 13 shows least square line L which could be obtained based on Point 1, Point 2 and Point 3. However, unintentional movement may occur and the direction of the Will Remote may be far away from the original direction. Thus, if the user shakes his/her hand and the fourth point $4'$ is far away from the original direction line L, the new least square line will become line L'. The noisy information will effect the recognition immediately, so the effect of noise should be reduced. In this paper, different weightings are assigned on new coming point and the original line direction to reduce the effect of noise. When the system detects a new coming point, this point will be vertically projected onto the original least square line to obtain the projected point. The system assign the weight of new coming point as 1/3 and the weight of projected point as 2/3. The new point's new coordinate will be obtained based on the weightings, original point and projected point. In Fig. 13, point 4 will be obtained based on the weighting mechanism mentioned above and it will replace the original point $4'$. Hence, the new least square line L'' will be obtained based on Point 1, Point 2, Point 3 and Point 4. Line L'' will be closer to the original line L than least square line L'.

4.4. Stroke direction identification

The system needs to identify hybrid strokes that involve more than one type. For example, in Chinese recognition, *Type 5* indicates combination of the stroke directions. In this paper, we proposed a novel approach, which is based on vector representation, to identify stroke directions. Every type except hybrid type is represented by a vector. As shown in Fig. 14, which is the classification of Chinese stroke direction, the unit vector for *Type 1* is $(1,0)$, the unit vector for *Type 2* is $(0,-1)$, the unit vector for *Type 3* is $(-1,0)$ and the unit vector for *Type 4* is $\left(\frac{1}{\sqrt{2}},\frac{-1}{\sqrt{2}}\right)$.

The trajectory vector is projected onto these basis vectors and the length of the projection is used to determine the strength of the trajectory on that direction. In essence, the projected length will be determined by the angle between these stroke vectors and the least square line. When the angle is less than 90°, the projected length will be positive. Otherwise, the value will be

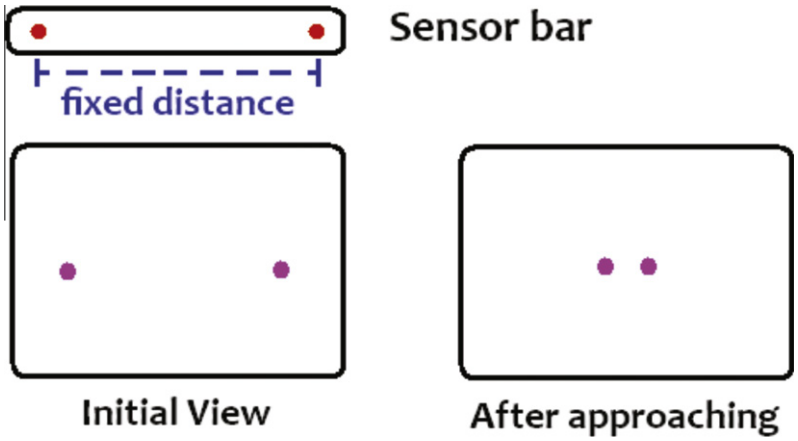

Fig. 11. Wii sensor bar IR sensor location.

Fig. 12. Vibration caused by unintentional movement.

negative. As with more points come into the least square line, the value for each direction will be accumulated and when the value exceeds a threshold value t, the system will output the stroke code which could be used to represent the direction of the least square line. Therefore, if the least square line involves two or more directions, this approach will output more than one stroke and it could be used to represent a hybrid stroke. As shown in Fig. 15, the projected values on $(1,0)$ and $\left(\frac{1}{\sqrt{2}},\frac{-1}{\sqrt{2}}\right)$ are positive, while the projected values on $(-1,0)$ and $(0,-1)$ are negative. Obviously, the projected value on $(1,0)$ is larger than the projected value on $\left(\frac{1}{\sqrt{2}},\frac{-1}{\sqrt{2}}\right)$. If the projected value on $\left(\frac{1}{\sqrt{2}},\frac{-1}{\sqrt{2}}\right)$ exceeds the threshold value t, the vector p will include two directions, *Type 1* and *Type 4*. Otherwise, the sequence code will output *Type 1* only.

4.5. Character recognition and fault tolerance

The recognition used in the system is based on stroke code matching. In other words, when the system obtains the trajectory information from the Wii Remote, the trajectory information will be encoded as code sequences. These code sequences will compare the code sequences stored in the database to acquire the corresponding characters or shapes.

In addition to strokes code sequences, the number of strokes, which will be used to filter out the words that are irrelevant, is another important features in Chinese and Japanese recognition. This feature could increase the accuracy of recognition. For some words whose code sequences are very short, exact matching of code sequence may blur the system's recognition. Therefore, some fault tolerance mechanisms for code sequences are proposed in this paper.

In Japanese recognition, the fault tolerance for adjacent area will be adopted to reduce the effect of vibration. Take the word appearing in Fig. 16 (pronounced as "to") as an example, its encoding is "24", so the result will be perfect if the system could recognize the input as "24". However, the Wii Remote controllers may vibrate and the trajectory may be a little different from the original one. Because Type 4 and Type 2 are both close to Type 1, the system will assign some scores to Type 4 even though the system recognizes the inputs as Type 2 or Type 1. If what the system detect is "25" or "23", no score will be assigned to Type 4. Since Type 3 and Type 5 are not the types that are close to Type 4, they are beyond the tolerance. This approach could enhance the fault tolerance capability of the system and improve system's recognition rate.

The recognition of English is quite different from Chinese and Japanese. One of the reasons is that most English alphabets are composed of only one stroke, so many stroke features could not be obtained. Therefore, the similarity between stroke code sequences are adopted to choose the best candidate character in the database. For example, the encoding sequence of character "b" is "3814". It means perfectly match if the trajectory information detected from Wii Remote is exactly "3814". However, trajectory information may include noise or lose some information during the movement, so fault tolerance mechanism is required to obtain the best result.

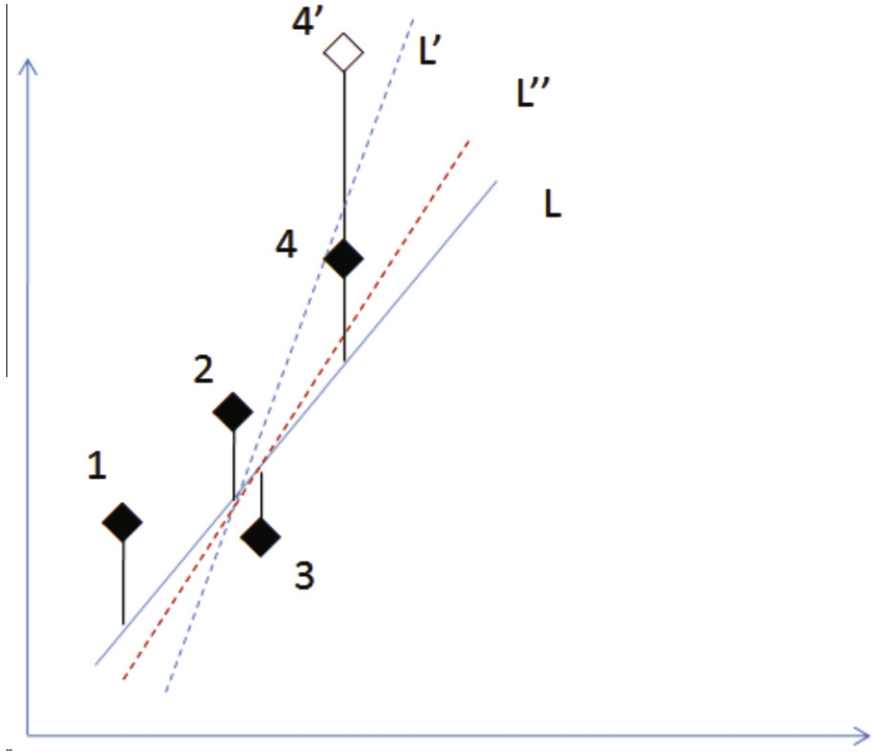

Fig. 13. Least square line adjustment.

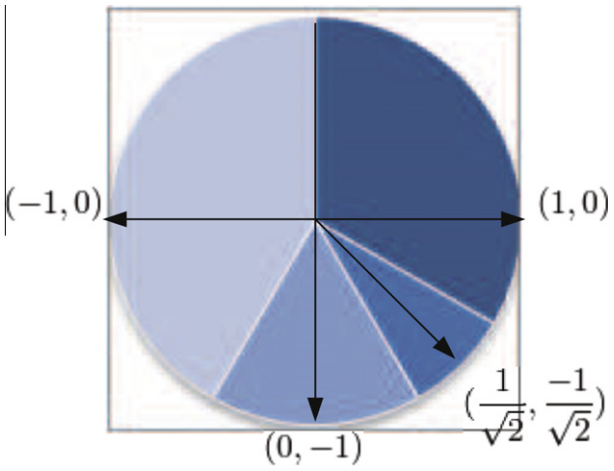

Fig. 14. Classification of trajectory vector.

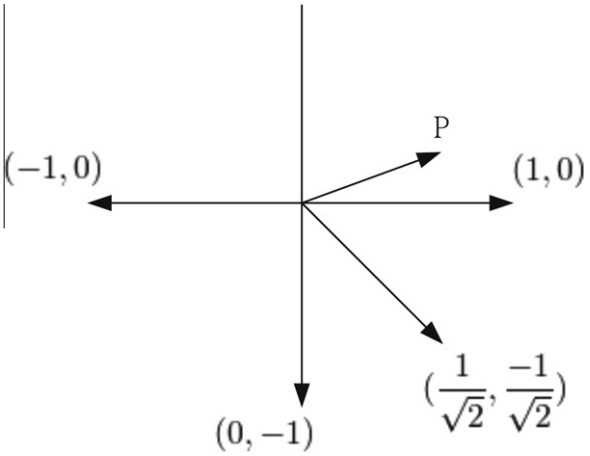

Fig. 15. Projection of trajectory vector.

Fig. 16. Japanese character example.

In information theory and computer science, the edit distance between two strings of characters is the number of operations required to transform one into the other. Edit distance measurement is adopted to determine the distance between two trajectory code sequences in this paper. If the trajectory information detected from Wii Remote is "314", the system could know the distance between "3814" and "314" is 1 from edit distance technique. It means that it is very close to the encoding of "b" character. In other words, the ranking of character "b" will be high.

4.6. Free sketch recognition and fault tolerance

In addition to basic painter functionalities, free sketch in our system includes triangle, rectangle and circle shapes recognition. Because there is no universal way for drawing, free sketch will not be limited by specific sequence of strokes. A triangle is a type of polygon having three sides and three angles. In geometry, a rectangle is a closed planar quadrilateral with four right angles. Thus, it

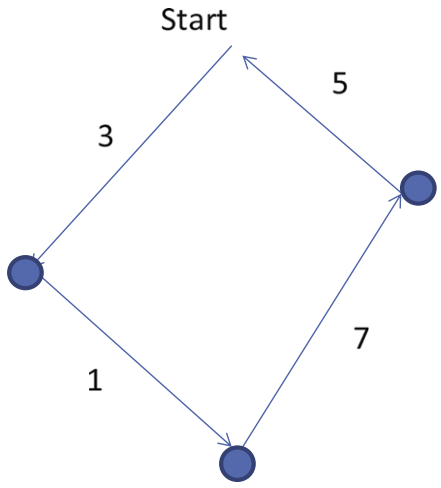

Fig. 17. Rectangle with stroke code "3175" and 3 turning points.

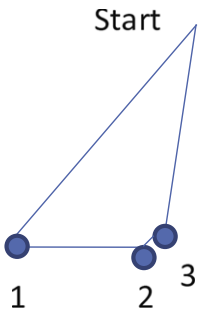

Fig. 18. Triangle trajectory with vibration.

is intuitive to adopt the number of turning points to recognize and distinguish triangle, rectangle and circle, respectively. In free sketch, a triangle is composed of two turning points, a square contains three turning points, and a circle is made by more than three turning points.

According to the trajectory code classification mechanism mentioned above, if the system receives trajectory data without noise, N turning points will output $N+1$ trajectory codes. Thus, the rectangle shape with stroke code "3175" will need 3 turning points as shown in Fig. 17. Unfortunately, unintentional vibration may occur when we paint in the air, when the direction of the movement is changed. As shown in Fig. 18, when the user holds Wii Remote to draw a triangle, unintentional vibration may generate additional stroke code in vertex 2. If the situation described above happens, three turning points are recognized by the system instead of two; as a result, it will effect the system's recognition.

Therefore, fault tolerance is required to solve this kind of problem. When the system detects four trajectory lines, an additional process will be proceeded to check whether it is a rectangle or not. In this paper, the trajectory sequence is used to detect right angle. As shown in Fig. 19, if the difference between consecutive stroke is two or six, the system will consider a right angle happening. Thus, if the system detects four trajectory lines or five trajectory lines, additional check of the number of right angles will be proceeded to check whether the shape is rectangle or not.

The system could not apply the method advocated by Nakai et al. (2001) because turning points can not be obtained by changes of speed and direction. When users hold the Wii Remote to write in the air, it is neither necessarily slower when a user draws a turning point, nor faster when drawing a straight line. Moreover, changes

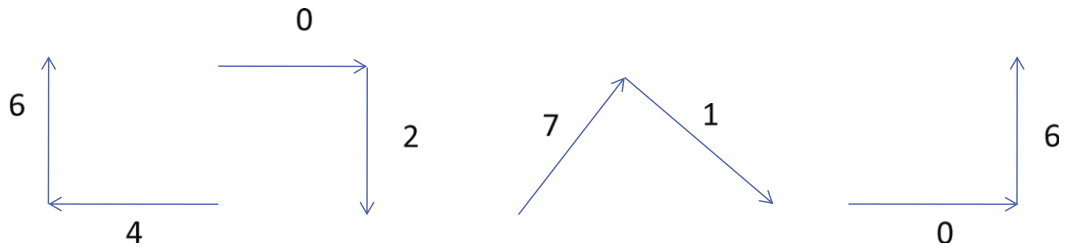

Fig. 19. Right angle judgment by stroke code.

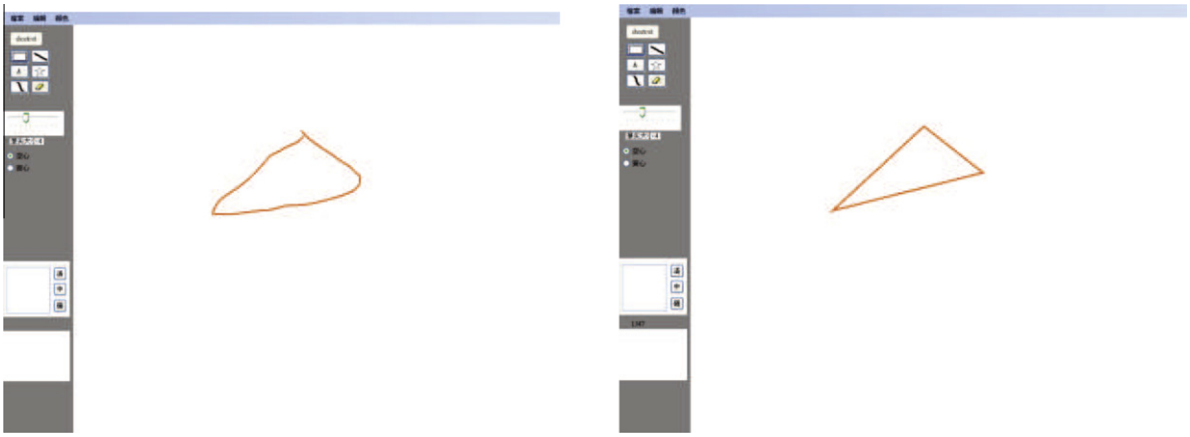

Fig. 20. Triangle recognition.

Fig. 21. Rectangle recognition.

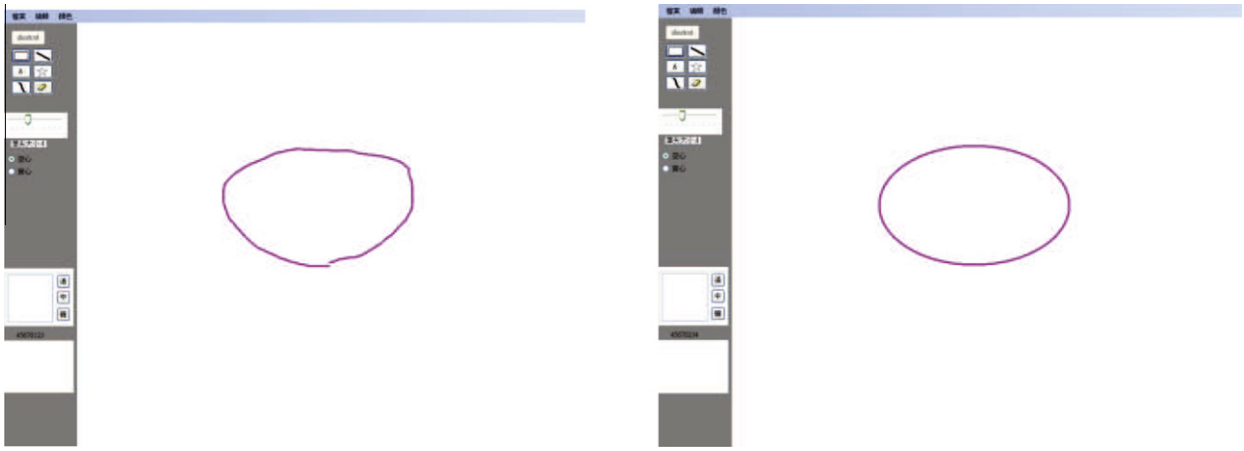

Fig. 22. Circle recognition.

Fig. 23. Screenshot of the system.

Table 1
Hardware and software list.

Input device	Wii Remote
Bluetooth	Billionton class 1 Bluetooth
CPU	Intel Core 2.13 GHz
DRAM	1 GB Ram
Bluetooth Driver	BlueSoleil 2.3
Infrared transmitter	Sensor bar of Wii
Wii communication software	GlovePie

Table 2
User experience result.

Easiness	Interest	Intuition
3.6	3.8	2.4

of direction are unstable due to the unintentional vibration. Fig. 20 shows the system's recognition of a triangle, and Figs. 21 and 22 show square and circle, respectively. Fig. 23 shows system screenshot.

5. Experiment and discussion

Table 1 shows the hardware and software list in the system. The functionalities provided by the system include basic painter functionalities, free sketch recognition, Chinese, English and Japanese character recognition. The user holds the Wii Remote as the input device and the trajectory information will be sent to the system through bluetooth connectivity. The system will encode the trajectory information and use the code sequences to recognize the characters and shapes. The goal of this experiment is to discuss the system's stability and user's experiences.

In the experiment, we invite 11 people, including 9 males and 2 females, to experience the system. All the males have the experiences of using Wii Remote, but the females do not. All the users are asked to use the functionalities of painting and handwriting recognition. The whole experiment lasts for 10 min. In the beginning of the experiment, all the testees are not used to Wii Remote controller to paint in the air. The testees who have the experiences of using Wii Remote can get used to the controller in 1 min; the ones who do not have experience of using Wii Remote can do it well in 10 min. Easiness, interest and intuition are used as evaluation indicators in the experiment. Easiness is used to evaluate whether it is easy to use Wii Remote to manipulate the painter system. Interest evaluation would like the users to feel whether the new input device is interesting. In intuition evaluation, we would like the users to determine whether user could get used to this device quickly as compared with mouse. Each participant will give a score ranging from 1 to 5 and a score of 5 is the highest. Table 2 shows the experiment result. The result shows that the users feel that it is not difficult to control Wii Remote and it is an interesting idea to use Wii Remote to construct an air painting system. However, most users feel that it needs some time to get used to this device as compared with mouse device.

According to the interview with the testees, they are interested in this novel input device, and they can accept this kind of input device. However, they feel it difficult to use the function buttons when they try to click the buttons, because their hands will move down a little bit unintentionally, and that will make the cursor vibrate. The experiment result also provides us the direction of how to enhance our system in the future. We have recently used Internet video to demonstrate our system and the video URL is http://www.youtube.com/watch?v=xQC6ZyXhfik.

6. Conclusion

In this paper, a unifying character and free sketch recognition scheme, which is based on the stroke code sequences, is proposed to process the recognition. One of the advantages of this approach is that the same mechanism could be applied to the whole system and it could incorporate the fault tolerance mechanisms proposed in this paper.

In handwriting recognition, Chinese, English and Japanese recognitions are included in the system. The users could use the Wii Remote as the input device and wave the controller in the air to manipulate the painter system. Practically, when the users hold the Wii Remote to write a character in the air, unintentional vibration may come to the system and produce many noisy information. Therefore, fault tolerance is necessary to reduce the effect of noisy information and the system needs to recover the information when trajectory information is missing. Several fault tolerance mechanisms are proposed in this paper to reduce the effect of noise.

In free sketch recognition, the system provides three shape recognition including triangle, rectangle and circle shapes. The number of strokes and right angles are important factors when the system performs the recognition of the shapes. Right angles recognition, which is based on the trajectory code sequences, could provide the fault tolerance for shape recognition. Meanwhile, the trajectory information provides the information for graphic sketching. The air painter system provides basic painting functions such as font, color, object movement, etc. Unlike traditional keyboard and mouse, the Wii Remote provides an innovative input manner for Human–computer Interaction systems.

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References

Glove programmable input emulator (glovepie). <http://carl.kenner.googlepages.com/glovepie>.

Hammond, T., Eoff, B., Paulson, B., Wolin, A., Dahmen, K., & Johnston, J. (2008). Free-sketch recognition: putting the chi in sketching. In *CHI '08: CHI '08 extended abstracts on human factors in computing systems* (pp. 3027–3032).

Hoque, S., Sirlantzis, K., & Fairhurst, M. C. (2003). A new chain-code quantization approach enabling high performance handwriting recognition based on multi-classific schemes. In *Proceedings of the seventh international conference on document analysis and recognition* (pp. 834–838).

Hu, J., Brown, M. K., & Turin, W. (1996). Hmm based on-line handwriting recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 18*(10), 1039–1045.

Kundu, A., & Bahl, P. (1988). Recognition of handwritten script: A hidden markov model based approach. In *International conference on acoustics, speech, and signal processing*, (Vol. 2, pp. 928–931).

Lee, J. C. (2008). Hacking the nintendo wii remote. *IEEE Pervasive Computing, 7*(3), 39–45.

Makhoul, J., Starner, T., Schwartz, R., & Chou, G. (1994). On-line cursive handwriting recognition using hidden markov models and statistical grammars. In *HLT '94: Proceedings of the workshop on human language technology* (pp. 432–436).

Marti, U.-V., & Bunke, H. (2001). Using a statistical language model to improve the performance of an hmm-based cursive handwriting recognition system. *International Journal of Pattern Recognition and Artificial Intelligence, 15*(1), 65–90.

Nag, R., Wong, K., & Fallside, F. (1986). Script recognition using hidden markov models. In *International conference on acoustics, speech, and signal processing* (Vol. 11, pp. 2071–2074).

Nakai, M., Akira, N., Shimodaira, H., & Sagayama, S. (2001). Substroke approach to hmm-based on-line kanji handwriting recognition. In *ICDAR '01: Proceedings of the sixth international conference on document analysis and recognition* (pp. 491–495).

Nintendo, Consolidated financial highlights (2009). <http://press.nintendo.com/docs/corporate/012809_FinancialHighlights.pdf>.

Plamondon, R., & Srihari, S. N. (2000). Online and off-line handwriting recognition: A comprehensive survey. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 22*(1), 63–84.

Sezgin, T. M., Stahovich, T., & Davis, R. (2001). Sketch based interfaces: Early processing for sketch understanding. In *Workshop on perceptive user interfaces, Orlando, FL* (pp. 1–8).

Starner, T., Makhoul, J., Schwartz, R., & Chou, G. (1994). On-line cursive handwriting recognition using speech recognition methods. In *International conference on acoustics, speech, and signal processing* (Vol. 5, pp. 125–128).