Development of Drawing Assist System
for Patients with Cerebral Palsy of the Tension Athetosis Type

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Abstract— Creative activities, such as painting and music, are one source of satisfaction and fulfillment for people with disabilities. However, some individuals with a disability cannot satisfactorily enjoy such activities because of involuntary movement or spasms. In this study, we developed a drawing assist system for patients with cerebral palsy of the tension athetosis type, who experience spasticity that makes it difficult for the assist system to distinguish involuntary movement from voluntary movement. We designed a variable filter to attenuate involuntary movement on the basis of the behavioral characteristics of the velocity component with respect to involuntary movement. Our system enabled drawing based on the participant's own senses and motor control, even when experiencing involuntary movement.

I. INTRODUCTION

Many people with physical disabilities enjoy creative activities as a means of self-expression. Painting is one such activity, and people with physical disabilities are able to draw pictures using residual functions. For instance, one can paint by using hand dexterity if the function of the arm is limited, or by using the mouth or lower limb if functional limitations affect the both upper limbs. In recent years, the development of assistive equipment and interactive software has brought creative activities based on computer graphics to people with disabilities [1]. Whether these creative activities can be satisfactorily enjoyed depends on the degree of the disabilities. Insofar as one's own body cannot be controlled as a result of involuntary movements, precise fine-motor movements become difficult to perform, thus limiting the ability to perform desired tasks such as painting.

To address these problems, studies have been conducted on systems that filter the effects of involuntary movements from the input signal of a device so that the on-screen pointer does not show unintended movement. IBM has reported that they explored the possibility of using a program that customizes the filtering mechanism to match the user's needs. However, this solution was impractical because even if the setup program runs successfully, involuntary movements

are not uniform but rather unpredictable, and tremor intensity changes over time, which necessitates frequent readjustment. Accordingly, the Assistive Mouse Adapter is developed by using a simple design that tunes the cut-off frequency of the linear low-pass filter by dialing [2].

In other work, Morimoto developed a painting tool that attenuates the effects of involuntary movements in real time[3]. In this attenuation method, smoothing by the moving-average method as well as the averaging switching and compulsory compensation methods were proposed as solutions for attenuating the effects of sudden shaking. The averaging switching method substantially increases the moving-average number when a displacement exceeds a certain threshold value. The compulsory compensation method takes an average of the drawing direction to create a straight-line reference axis. Next, the compulsory compensation method replaces any input coordinates that deviate a specified distance from the reference axis with coordinates on the reference axis. These methods are effective for patients with partial paralysis, who can move and click a mouse on a table. However, for patients with severe spasticity, these methods are ineffective because of the difficulty of keeping the input device on a plane, as well as because of the irregularity of the involuntary movement and its variable strength. In addition, the frequent occurrence of sudden shaking requires the moving average to maintain a high value which results in deterioration of manipulation performance and decreased intuitiveness of assisted drawing. Against this background, a drawing assist system is desired that offers superior manipulation performance and can be used by people who experience strong, irregular involuntary movements.

Here, we propose a method of variable filtering to correct for unintended input from involuntary movement in real time and develop a drawing assist system that enables even individuals with strong, irregular involuntary movements to draw pictures. Finally, the results and the intuitive operability of our proposed method are demonstrated through a drawing experiment, in which the participant is an individual with cerebral palsy of the tension athetosis type.

II. DRAWING ASSIST SYSTEM FOR PATIENTS WITH CEREBRAL PALSY

Cerebral palsy is a disease characterized by involuntary movements; the condition results from damage to the motor control centers of the brain before, during, or shortly after birth [4]. In particular, the involuntary movements of patients with cerebral palsy of the tension athetosis type

occur suddenly and are dramatically worsened by exertion. These involuntary movements manifest when a person with the condition attempts to maintain posture or sustain a certain movement; also, the muscle tone of people with athetoid cerebral palsy increases with postural maintenance and decreases while at rest [5].

An individual with cerebral palsy of the tension athetosis type consented to participate in this study. Whenever she starts to move her body, it results in strong, sudden involuntary movements, and straining to control the movements only worsens them. Therefore, it is difficult for her to perform many activities in daily life, and she receives around-the-clock assistance. On the other hand, she can manipulate a custom-adapted computer keyboard by herself and enjoy creative activities such as painting and composing *tanka* (traditional Japanese poems). While using the computer, she tucks her left arm between the left arm of her chair and her body. She then manipulates the keyboard with her comparatively controllable ring finger and little finger. To compensate for the limited range of movement possible using only two fingers, her keyboard has a slider that moves from left to right and a plastic keyguard for preventing typographical errors. The pointer is manipulated with the numerical keypad on the keyboard instead of with a mouse.

Her usual means of painting is simply 'coloring in' within the lines of an existing drawing. She expressed a strong desire to draw pictures on a computer like on real canvas, but this could not be achieved using only current assistive devices and setups. When considering an input device for a patient with severe spasticity, a graphics tablet is unsuitable because postural maintenance on a plane, such as controlling a mouse or graphics tablet, is necessary; instead, a device that can move in three dimensions and measure three-dimensional coordinates is required. An additional concern is that the participant sometimes involuntary releases her grip on objects ; for example, if she were to release and drop a graphics tablet, it would be almost impossible for her to pick it up by herself.
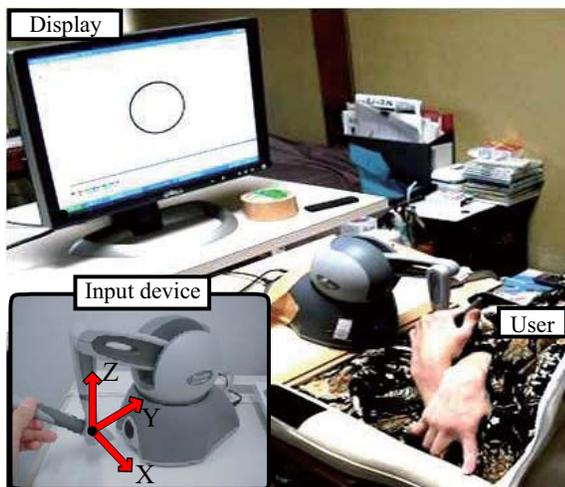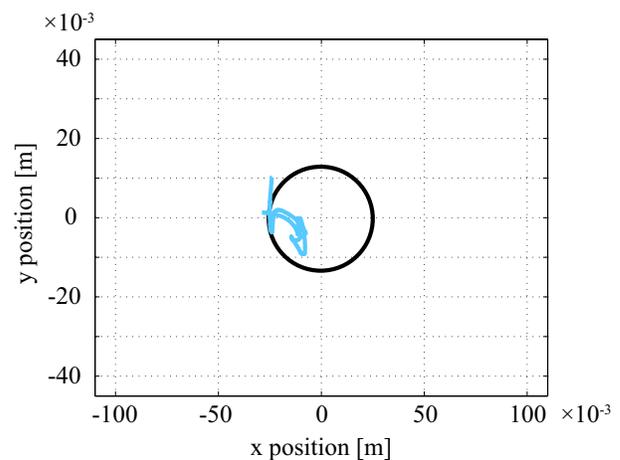

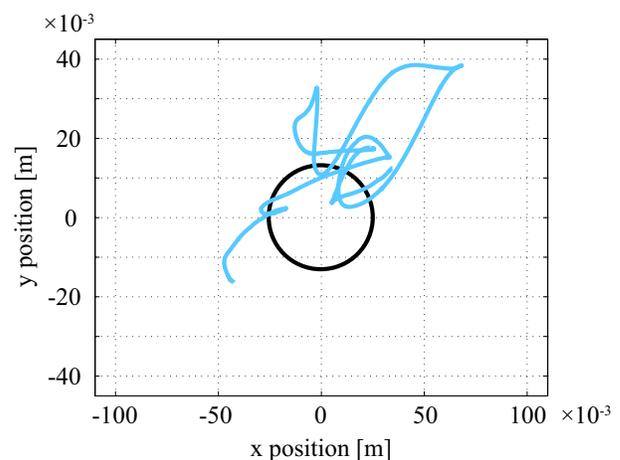Fig. 1.   Experimental setup for drawing assistance system

Taking the above points into consideration, we constructed a drawing assist system using a compact haptic interface, namely, the PHANToM Omni (SensAble, Inc.) [6], as an input device. The experimental setup of the device is shown in Fig. 1. In this system, left–right movement corresponds to the x axis, and up–down movement corresponds to the y axis.

III.   ANALYSIS OF INVOLUNTARY MOVEMENTS

As a preliminary experiment to design a variable filter for removing the effects of involuntary movements, we conducted a manipulation test of the input device with the participant. In this particular experiment, the participant tried to keep the pointer inside a circle of 280 pixels (0.08 meters) in diameter on a display. Design of circle is considered with viewability on a display, stress and movements of pilot experiment. Figure 2 shows changes in the position of the pointer on the x-y plane during two 2 [s] periods, taken from data on a series of manipulating movements.
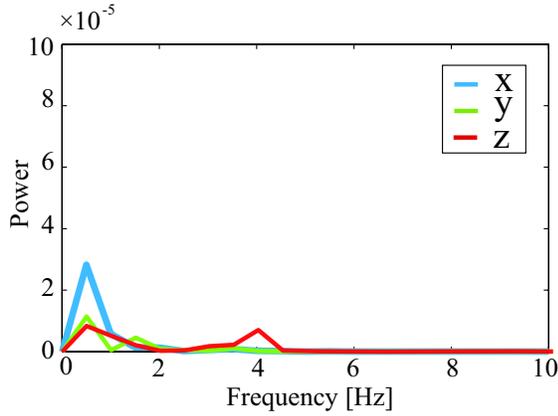

(a) Weak involontary motion
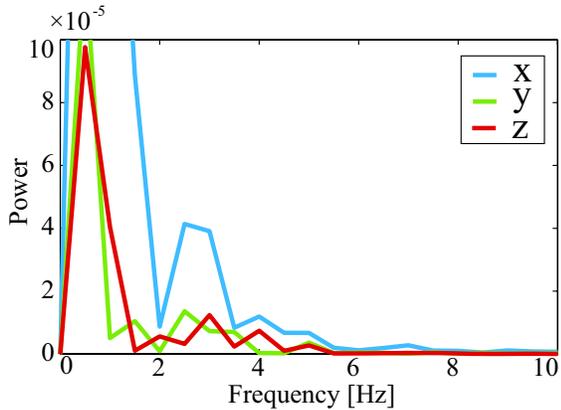

(b) Strong involontary motion

Fig. 2.   Involuntary movements on the X-Y coordinate plane

From this result, we evaluated the effects of both continuous weak involuntary movements as shown in Fig. 2(a) and sudden strong movements as shown in Fig. 2(b). It is

difficult for her to manipulate the device because her strong involuntary movements do not reflect her desired input. First, the frequency analysis with FFT for each axis is carried out to clarify frequency characteristics of voluntary movements. The result of frequency analysis is shown in Fig. 3. From comparison between week and strong involuntary movements, predominant frequencies of both involuntary movements are in the low-frequency region. Most voluntary movements in daily life are in the low-frequency region; thus, if a damping method using a regular notch-filter were applied, it would dampen not only involuntary movements but also voluntary movements, in turn preventing recognition of the user's desired input.

(a) Spectrum of weak involuntary motion
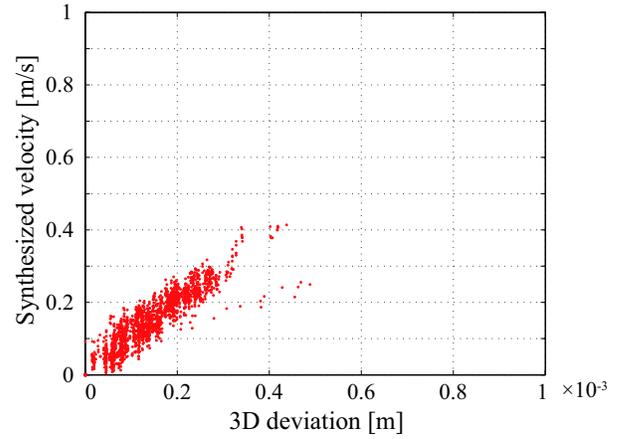

(b) Spectrum of strong involuntary motion

Fig. 3.   Spectrum of involuntary motion

Next, we focused on the change in velocity instead of frequency characteristics and conducted an analysis using the synthesized velocity as an index. The formula for computing the synthesized velocity is
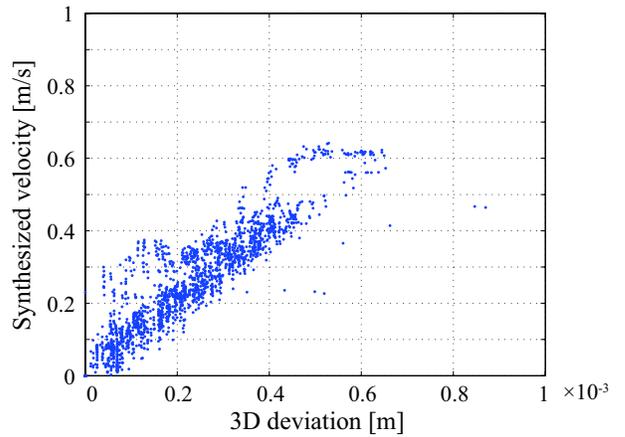
$$v_{3d} = \sqrt{v_x^2 + v_y^2 + v_z^2}, \qquad (1)$$

where v_x, v_y and v_z are velocities on x, y and z axes. The relation between the synthesized velocity and the three-dimensional deviation between two consecutive samples is

shown in Fig. 4. Figure 4(a) shows the results for weak involuntary movements, and Fig. 4(b) shows the results for strong involuntary movements.

(a) Weak involuntary motion

(b) Strong involuntary motion

Fig. 4.   Relation between deviation and velocity

The results for the weak involuntary movements reveal that the upper range of synthesized velocities was from 0.3 to 0.4 [m/s], and the synthesized velocities for frequent movements were around 0.2 [m/s]. Similarly, the results for strong involuntary movements show that the upper range of synthesized velocities was from 0.6 to 0.65 [m/s], and the synthesized velocities of frequent movements were in the range of 0.35 to 0.45 [m/s].

As a result, we verified an increase in the synthesized velocity with three-dimensional deviation; in other words, there is a nonlinear relationship between synthesized velocities and three-dimensional deviation. Therefore, the synthesized velocities are useful as an index to distinguish between weak and strong involuntary movements.

IV. DESIGN OF THE VARIABLE FILTER

The filter was designed on the basis of the results of the above analysis by changing the degree of attenuation of the moving-average method in response to changes in the

synthesized velocity. The weight coefficient of attenuation w_i is given by

$$w_i = \frac{\alpha T^n}{T^n + v_{3di}^n}. \tag{2}$$

The corrected point G_i is calculated using the moving-average method as follows:

$$G_i = G_{i-1} + \frac{w_k}{NS} \sum_{k=i-NS}^{i} (P_k - G_{i-1}). \tag{3}$$

Here, P is measured position, the moving-average period is N=2.0[s], the maximum weight is $\alpha = 1.0$, and the order is $n = 3$. The sampling frequency S is 7500. The cut-off velocity T making $w_i = 0.5$ is set as 0.3 [m/s] because the maximum synthesized velocity of weak involuntary velocity is around 0.3 [m/s]. As shown in the equation (3), the corrected point G_i is updated with the weight coefficient of attenuation w_i and mean distance of measured positions during 2.0 [s] from a past corrected point G_{i-1}. The change of weight coefficient in response to the change in synthesized velocity is shown in Fig. 5. For this weight coefficient, the degree of attenuation comes near simple moving-average method at low synthesized velocities equal weak involuntary movements, but it is risen at high synthesized velocities equal strong involuntary movements.
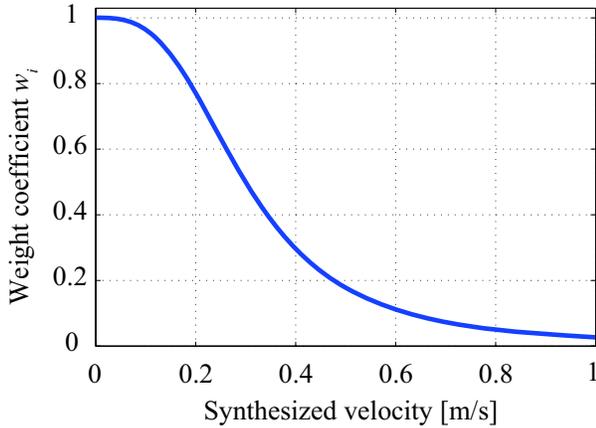
Fig. 5.   Change of weight coefficient with respect to velocity

In addition, the measured data from the input device was converted to the coordinates of the on-screen pointer $P_D = [x_D \; y_D]$ with the following equation:

$$P_D = (G + \frac{L_P}{2}) \times \frac{L_D}{L_P}. \tag{4}$$

Here, $L_P = [L_{Px} \; L_{Py}]$ is the range of movement of the input device, and $L_D = [L_{Dx} \; L_{Dy}]$ is the size of the on-screen drawing region.

The applicability of the variable filter to measured data on involuntary movements was verified in the following way. First, we carried out an experiment to determine the relationship between change of the moving-average period N and the attenuation of the effects of involuntary movements. The task of this experiment is in the same way of analysis of involuntary movements. The results are shown in Fig. 6.
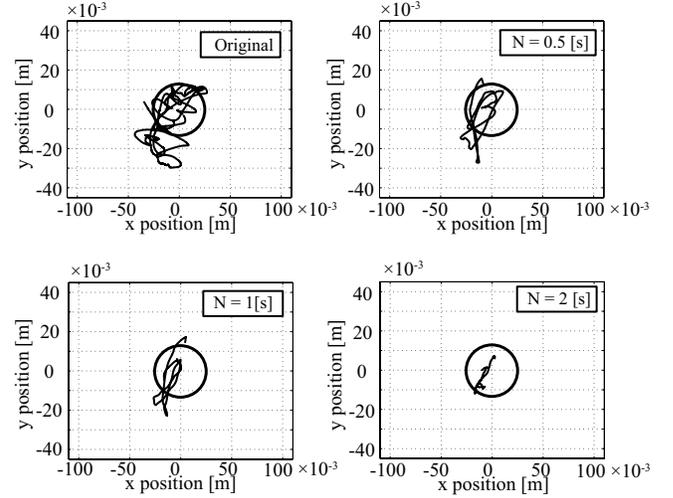
Fig. 6.   Attenuation of the effects of involuntary movements for various moving-average periods

As a result, we found that the degree of deviation from the reference circle decreases with increasing N. However, there is the trade-off in that the manipulation performance also decreases with an increase in N and therefore results in an increase in delay. The suitable moving-average period of N = 2.0[s] for the participant was determined through repeated tests and feedbacks from a user.

Next, we carried out an experiment to compare normal moving-average method with our variable filter. The task of this experiment is in the way of making a counterclockwise turn from lower right. The trajectories modified by the moving-average method and our variable filter are shown in Fig.7. From this result, we verified that the trajectory modified by the moving-average method attenuates the effects of involuntary movements, but a repulsive trajectory in the area around the origin can be found. Therefore, the moving-average method is inconsistent for attenuating strong involuntary movements. In contrast, the variable filter attenuates the effects of strong involuntary movements successfully.

V. DRAWING ASSIST EXPERIMENTS

In the case of a patient with cerebral palsy of the tension athetosis type, we should consider that stress and strain lead to strong involuntary movements. Moreover, manipulation that requires precise movements will induce strain. In this study, the participant first moved her arm within an image of a drawing without inhibition. Then, drawing conditions were set up by analyzing and extracting the characteristics of her movements.

Drawing conditions were the size of the on-screen canvas and the criterion for starting to painting. It was necessary to
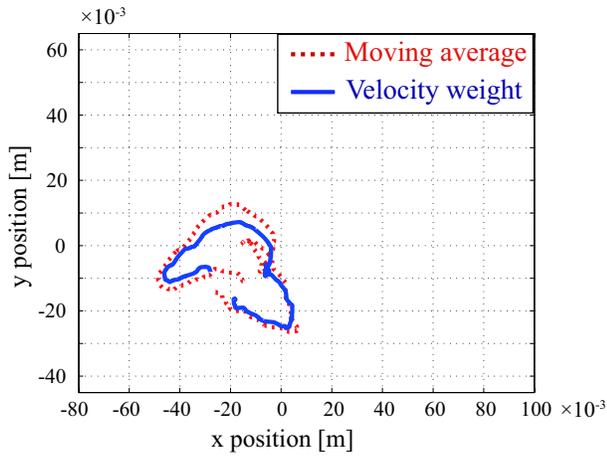
Fig. 7. Comparison of correction effect using method of moving average with velocity weighted coefficient

set an appropriate size of canvas for the participant because the limited range of movement of her left arm affected her manipulation of the input device. Furthermore, judging whether the tip of the brush makes contact with the canvas at the start of painting is necessary. The experiment to set the drawing conditions was carried out as follows. A rectangular grid consisting of four rectangles was displayed and the participant was asked to imagine a canvas in each rectangle of the grid. Then, the participant was instructed to trace the outline of the canvas within each rectangle using the device with the variable filter. The order of painting was counterclockwise from lower right to lower left. When the participant felt that she had painted well, she said "Yes". A single trial consisted of one revolution from lower right to lower left, and six were carried out in total. Focusing on the movement exhibit on the x-y plane, we measured the results of change in position as shown in Fig. 8.
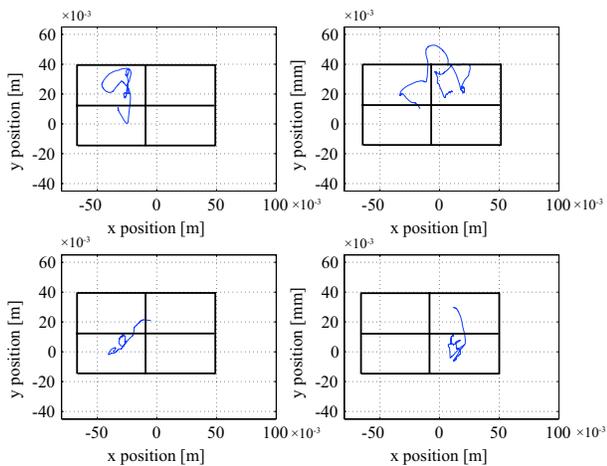

Fig. 8. The drawing motion on X-Y coordinate

Because the participant was able to indicate all four rectangles of the canvas with admissible accuracy over six trials, we were able to correlate the converted measured data from the input device with the coordinates of the canvas

(Table I). From this data, the criterion for starting to paint was designed and is given in equation (5), on the precondition that the deviation between the current coordinate on the z-axis and before 0.5 [s] is over 50 [mm]. We have verified that the participant could manipulate the input device under these conditions without problems.

TABLE I
SCALING RELATIONSHIP BETWEEN INPUT COORDINATE AND DRAWING POSITION

	Unit	Min	Max
L_{Px}	m	-0.03	0.03
L_{Py}	m	-0.015	0.055
L_{Dx}	pixel	0	1024
L_{Dy}	pixel	0	780

$$\Delta z = |z(t) - z(t - 0.5)| \geq 50 \qquad (5)$$

With the developed system, the participant was able to draw pictures. She drew pictures of flowers using a painting technique called *stamping*, which is used for coloring and mimics stamping a real canvas with various items, such as sponges and cloth balls. The free software *OTOSIMIZU*[7] can imitate watercolors to give a graded effect depending on input time and strength. The leaves were drawn using the vector graphics tools, rather than free-hand drawing, that the participant usually uses. The flowers were created by using the drawing assist system to implement the stamping technique.

The behavior of input data over a 10-min drawing period is shown without a variable filter in Fig. 9 and with a variable filter in Fig. 10.
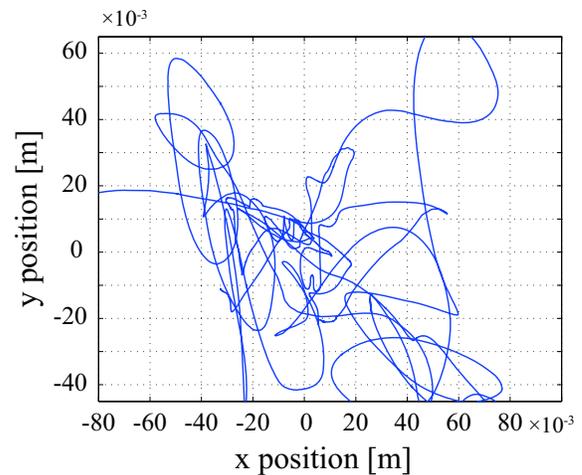

Fig. 9. Original signal for the drawing "Flowers"

It is apparent from these figures that the behavior of the pointer without a variable filter is characterized by irregular direction of movement and movement distance, which occur when there is a high frequency of changes of direction or when the participant cannot maintain the intended position.
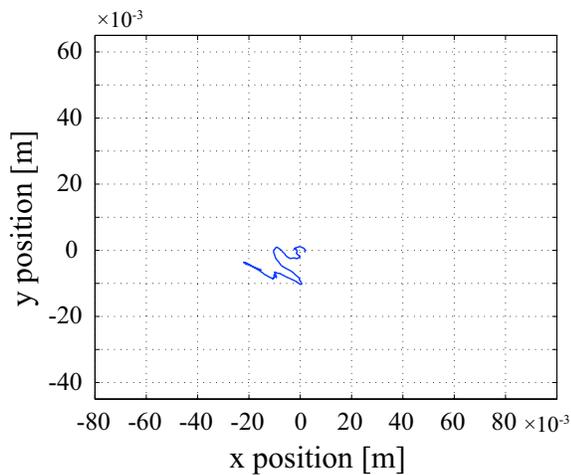
Fig. 10. Filtering signal for the drawing "Flowers"

The picture painted without the variable filter is shown in Fig. 11, and with the variable filter in Fig. 12.
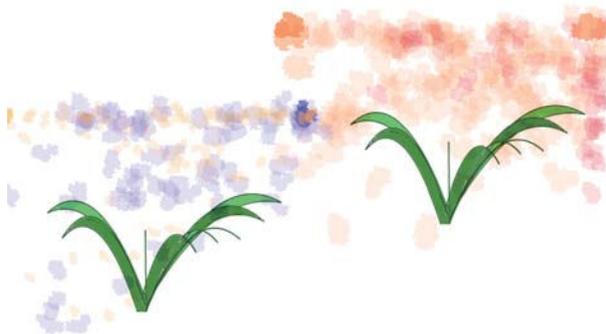

Fig. 11. "Flowers" drawn by the participant (original signal)

Without a variable filter, painting is erratic across the entire canvas. With the filter however, painting is smooth and stable within the active region, and painting around the intended position can be achieved. Although the result in this case was only a simple picture, the participant was able to draw independently as a means of self-expression with the aid of the drawing assist system.

VI. DISCUSSION

We have continuously carried out examinations and obtained feedbacks every time. As comments of the participant; "I had fun and want to paint more." "That system is very interesting! I feel like I'm drawing pictures because of hand drawing. I want to use it." "I hold up a hope to this system for a way of drawing." From her comment, we can find she enjoyed it, became to like our system and felt the system was intuitive to use. Additionally she had aspiringly proposed designs of picture for examination. We received requests that it is better that the speed of pointer is slow for processing and the length of stylus is long for device. These feedback
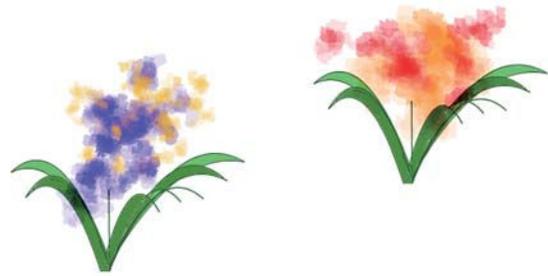

Fig. 12. "Flowers" drawn by the participant (with filtering)

and experimental result indicate that this system can be use intuitively and provide one source of satisfaction and fulfillment for the participant.

This is foundation study with respect to drawing assist system. Because we couldn't get the cooperation of medical institution, the participant is only an individual not several patients with cerebral palsy. As future works, we will encourage medical institution, get the cooperation and carry out examinations and statistical verification for more patients.

If our method can be developed more in the future, it might be useful not only for drawing but also for writing words in education, additionally as a handle assistance system for driving a car, electric-powered wheelchair and other assistance robots and so on in many ways for patients with various cerebral palsy.

VII. CONCLUSION

In this study, we developed a drawing assist system for patients with cerebral palsy of the tension athetosis type by using a variable filter with synthesis velocity. The variable filter successfully attenuates the effects of the involuntary movements that result in irregular direction of movement and movement distance and caused by a high frequency of changes of direction. The intuitive operability of our system was verified by a drawing assist experiment with a participant with cerebral palsy of the tension athetosis type.

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