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Real-Time Analog Input Device Using Breath Pressure for the Operation of Powered Wheelchair

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Abstract— **The severely handicapped often uses breath pressure for an input method to control various instruments such as TV, motorized bed, curtain, air conditioner in everyday life. Most of the input devices are ON/OFF (digital) type for the control of equipments. Considering the application of electrically powered wheelchair, the ON/OFF type interface is not desirable. Because the control of powered wheelchair needs preciseness and quickness for safe operation. A new input device using breath pressure is proposed for such purposes. The paper examines basic performances of human breath pressure control as an analog input device. Then possibility of two-dimensional input device by the breath pressure is discussed for the control of powered wheelchair. Basic experiments to study performance of the two-dimensional analog input device by breath pressure for an operation of the powered wheelchair are shown.**

Index Terms— **Breath Pressure, Two-dimensional Analog Input Device, Powered Wheelchair**

I. Introduction

The severely handicapped can use environmental control systems (ECS) as a tool for self-reliant[1]. They can control powered bed, powered curtain and window, television, telephone, air conditioner, etc. by themselves using remaining function such as chin, mouse, eye motion or breath pressure. This study proposes a new interface technique using remaining function of the severely disabilities for self-reliant.

Digital (ON/OFF) switching operation has been often used to control various machines such as changing TV channel and changing the angle of powered bed as a user-interface for the severely disabilities. Most machines can be operated by such digital switching operation. The ON/OFF switching information is obtained by various methods such as pressure sensor[1], [2], tongue contact sensor[3] and voice command[4] using the remaining functions of the disabilities. However, real-time analog operations are also needed under a situation such as powered wheel chair operation for quick and accurate safety control. For such purpose like powered wheelchair, digital type interface is not appropriate because of the safety reason. Conventional operation device for the powered wheelchair is control stick for the disabilities. When it is hard to use the control stick by the severely disabilities, the method is not available.

For such reason, some analogue type human-interface for disabilities have been proposed, such as the interface using EMG[5] and motion of head[6]. However It is difficult to realize safe and stable operation using the interfaces. We have proposed a new user-interface method[7], [8] to realize real-time analog input as an input device of various welfare machinery and ECS for the severely disabilities. In this study, basic performance such as the characteristic of frequency response for the new input method is investigated experimentally. Then mouth part for the input device is designed for the control of powered wheel chair. Control law using the value of breath pressure is also proposed for the safety control. Experiment of the control for the powered wheelchair using the proposed new input method is shown.

II. Regulation Performance of Breath Pressure

A. Human Respiration

It is believed that human respiration (breath rhythm) is generated by inspiratory neuron and expiratory neuron in the brain stem which is called respiration center. The function of respiration works usually unconsciously. However, we can also change the breath rhythm consciously. This study uses the conscious respiration as a remaining function of the severely handicapped people. In this method, we have to note that the use of conscious respiration should not interfere the normal respiration for ventilation.

This section shows results of basic performance experiments as an input method by breath pressure. In the experiment, subjects regulate their breath pressure according to the specified pressure level which is shown in CRT display as shown in Fig.1. The regulation process is done by eye, brain, neural and diaphragm. There are probably different routes for the process for the case of being predictable for near-future changes (specified pressure level) and for the case of being unpredictable for the near-future changes. We thus examine the two cases of basic regulation performances for human breath pressure control.

B. Breath Pressure Sensor

Normal human breath pressure is around ±2KPa with relative air pressure. We thus use a micro manometer sensor (Fujikura 005KPGW: piezoelectric semiconductor

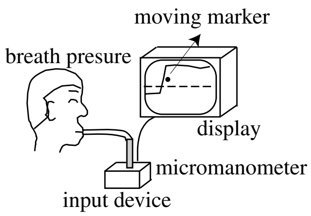

Fig. 1. Breath pressure step response experiment by showing a moving marker

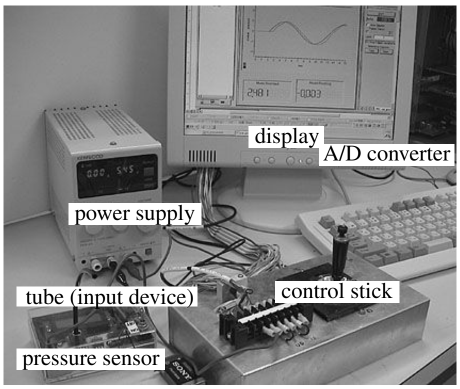

Fig. 2. Tube with breath pressure sensor and control stick as input devices

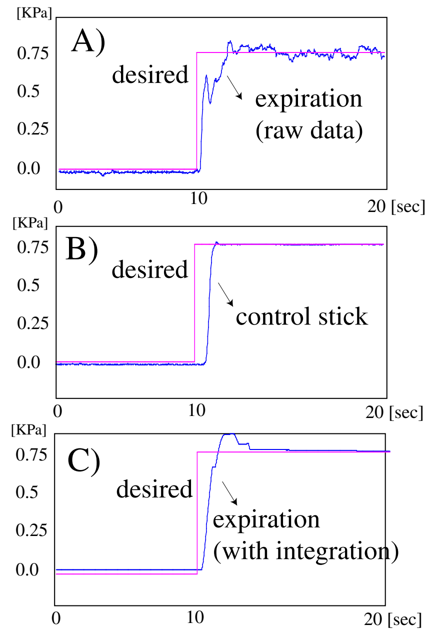

Fig. 3. Step responses of expiration pressure and control stick position

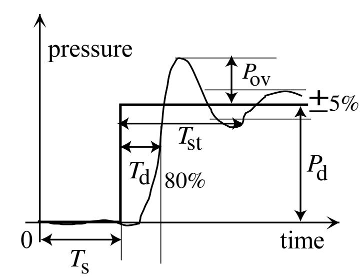

Fig. 4. Performance parameters for step response of breath pressure

type pressure sensor) with the range of ±5KPa. The sensor outputs voltage in proportion to human breath pressure. Using an A/D converter, the pressure is measured by a PC. A subjects holds a pipe in his (her) mouth. The other side of the pipe is connected to the pressure sensor. Actual experimental setup is shown in Fig.2 which includes analog control stick for a comparison with normal manual operation.

C. Regulation Performance of Compensation Type

This section shows experimental results to examine human basic regulation ability of breath pressure. The regulation performance is examined by step response for unpredictable timing and unpredictable level of pressure value. The regulation is done only by the information of visual information, which is called compensation type. Subjects regulate their breath pressure to follow the displayed desired step.

At first, using the pre-setting constant value of pulse rise time T_s and desired pressure P_d, subject trained the breath pressure regulation. After several trainings, typical human step responses of direct expiration pressure is shown in Fig.3 A). For comparison, typical step response by control stick's regulation is also shown in Fig.3 B).

From the figures, we can see that breath pressure response vibrates near desired value. Thus, it is hard to use directly the breath pressure for the input interface. Then we use integrated pressure value as response value instead of using direct breath pressure value. The step response of the integrated expiration pressure value is shown in Fig.3 C) From this result, it is found that the performance of the step response using integrated breath pressure is almost same as the performance of control stick's one. It is desirable for normal ventilation to adopt integrated breath pressure value, because when users leave their mouth from the pipe (input interface by breath pressure) for normal breath, the input value keeps the current value by using this method.

To examine basic performance of human regulation ability for breath pressure with more simple condition, the parameters pulse rise time T_s and desired pressure P_d (see Fig.4 for the notation) are randomly given in the next experiment. In this case, subjects have to regulate their breath pressure only by visual feedback for the information of CRT monitor. The flow of information process for the case is represented by a block-diagram of Fig.5. We call this as ”compensation type performance experiment”.

Table 1 shows the result of the compensation type

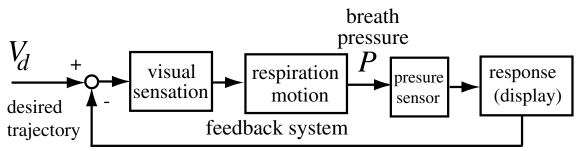

Fig. 5. Step response by feedback type process

TABLE I

COMPARISON OF STEP RESPONSE USING EXPIRATION, INSPIRATION PRESSURE AND CONTROL STICK (THE MEANINGS OF THE PERFORMANCE PARAMETERS ARE SHOWN IN FIG. 4)

	T_d[sec]	T_{st}[sec]	P_{ov}[KPa]
breath(+)	1.62	3.14	0.134
breath(–)	2.29	3.48	0.125
control stick (+)	0.92	1.82	0.047
control stick (–)	0.94	1.91	0.049

performance experiment. Where T_d is time delay (time to 80% of desired value), T_{st} is stabilization time (time within ±5 % of desired value), maximum overshoot P_{ov}. Step responses using integrated pressure value of expiration (breath +) and inspiration (breath -) for each value T_d, T_{st}, P_{ov} are shown in the table. These are mean values by 10 trials for three healthy subjects. For comparison, the values for the case of control stick are also shown in the same table. Where control stick (+) means pushing side operation and stick (-) means pulling side operation of the control stick.

The pulse rise time T_s and desired pressure P_d are randomly given in this experiment. By this result, it is found that the performance of breath pressure regulation is inferior to control stick case in the vale of around twice for time delay T_d, stabilization time T_{st}, maximum overshoot P_{ov}. Interestingly, regulation performance of inspiration (negative pressure) is inferior to the performance of expiration (positive pressure).

D. Regulation Performance of Predict + Compensation Type

In the previous subsection, we've proposed that use of integrated breath pressure value instead of direct pressure for an input interface method. Then it is found that the method can be used as an input user interface even though the performance of the regulation is inferior to the case of control stick a little bit.

Considering the operation of powered wheelchair, the desired trajectory such as footpaths and corridors are predictable in advance in a certain extent for most cases. It may be not appropriate only to examine the performance of compensation type. Thus, we next examine another basic regulation performance for such case.

In this experiment, a sine curve is displayed on CRT in advance. Then a marker moves along the direction of time axis (X-axis). On the other hand, position of the

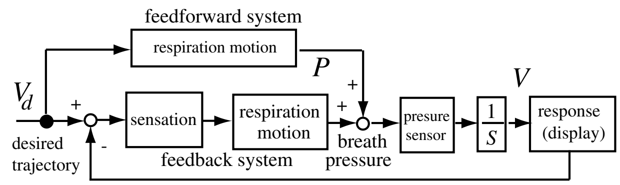

Fig. 6. Block diagram of breath pressure control system for the response of predict + compensation type

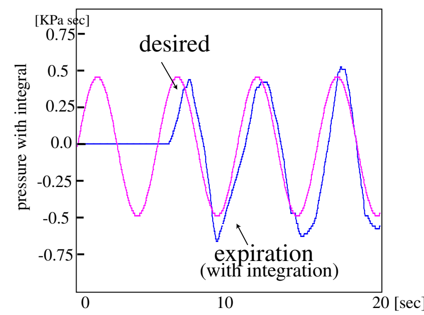

Fig. 7. Response of breath pressure for a sine curve

marker for Y-axis is changed according to the specified integrated breath pressure value by subjects. The subjects follow the specified sine curve using the moving marker by regulating their breath pressure. In the experiment, feedforward part based on the pre-specified information of desired trajectory (sine curve) and feed-back process of fine control by deviation between the desired trajectory and actual response trajectory are considered. Thus, we call this experiment predict + compensation type regulation. The information processing route for this case is shown in Fig.6.

A typical response (integrated breath pressure) of this experiment is shown in Fig.7. Characteristics of frequency response of the human breath pressure is investigated by the experiment for different frequency of sine curve. The result of frequency response is shown in Fig.8. The plotted ones are mean values measured by 10 trials for three healthy subjects. For the comparison with control stick by manual

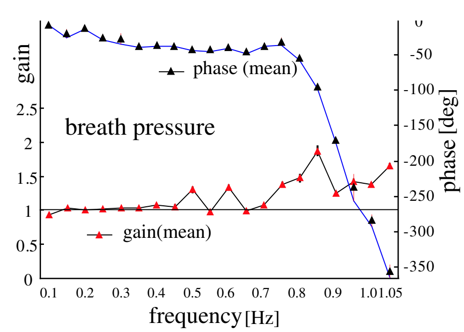

Fig. 8. Frequency response of breath pressure

operation, the frequency response for the case is also shown in Fig.9. These frequency responses are obtained by mean value of five times trials.

It is found that the response until 0.9Hz by breath pressure and response until 1.2Hz by control stick are possible as the input interface. The breath pressure can be used as a real-time analog input interface, even though the ability of breath pressure regulation is a little bit inferior in the response speed comparing with conventional control stick.

E. Effect of Integral Constant

As presented in the previous subsection, the method of integration of breath pressure leads to good steady state characteristic as an input interface. Constant parameter of the integration affects the performance as an input interface. The integration of breath pressure is described by

$$v(t) = v_0 + k_i \int_0^t g(p_b(t) - p_0)dt \qquad (1)$$

$$g(*) = \begin{cases} 0 & (|*| < p_{noise}) \\ * - p_{noise} & (* \geq p_{noise}) \\ * + p_{noise} & (* \leq -p_{noise}) \end{cases}$$

where the k_i is integral gain, p_0 is atmospheric pressure, p_{noise} is a constant to remove sensor's noise.

The integration of breath pressure enables stable operation as a human interface, however, too much value of the integration constant may lower the response speed. We thus examine response of time delay T_d, maximum overshoot V_{ov} and aerial error for steady state S_{dev} (see Fig.10) for the various values of the integral constant k_i.

Figure 11 plots the value of T_d, V_{ov}, S_{dev} for various integral constant k_i. The upper figure is the result of expiration (positive breath pressure) and the lower one is the result of inspiration (negative breath pressure). By this result, response speed (T_d) and response accuracy are a trade-off relationship each other. It is found that we can set optimal integral constant satisfying both performances of response speed and response accuracy using the result. For example optimal integral constant is indicated by an arrow in Fig.11.

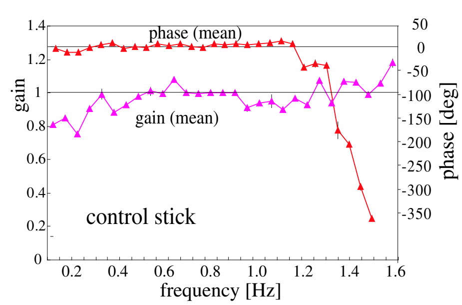

Fig. 9. Frequency response of control stick

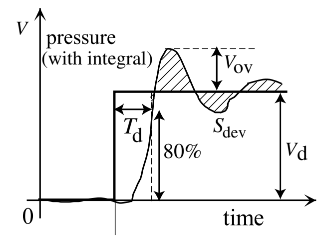

Fig. 10. Performance parameters for step response

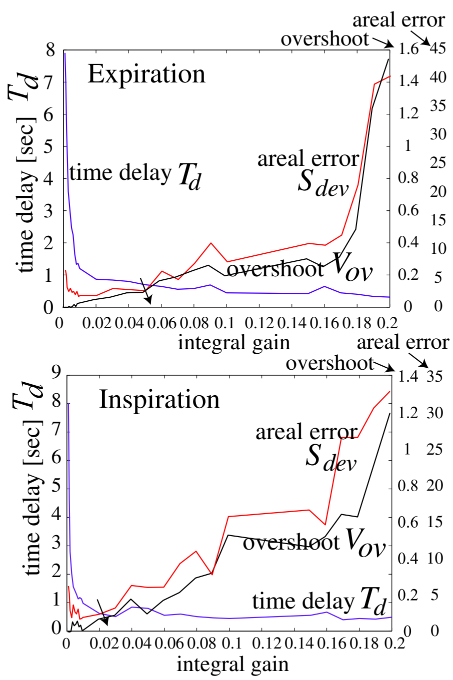

Fig. 11. Performance of step response for various integral gains

III. Two Dimensional Input Device and Operation of Powered Wheelchair

We have examined the performance of regulation by breath pressure as a one-degree-of-freedom analog input device. When we consider this breath pressure interface as an alternative method for control stick, we need to realize two-dimensional real-time analog input.

Considering the breath pressure as an two-degrees-of-freedom input device, it seems hard to realize the two-degrees-of-freedom by one mouth. When we make a mouth part by combining two pipes of this breath pressure interface as shown in Fig.12, we can not breathe in and out at the same time. Thus, only region I and III are available in Fig.12 using this adjacent two pipes. Where the figure means coordinates for left pipe's breath pressure value by horizontal axis and right pipe's breath pressure value by vertical axis. For example, the region I means that positive pressure for left pipe and right pipe are added and the region II means negative pressure for left pipe and positive

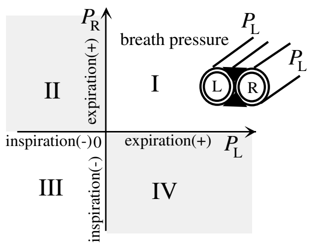

Fig. 12. Possible region for the input of 2-DOF case

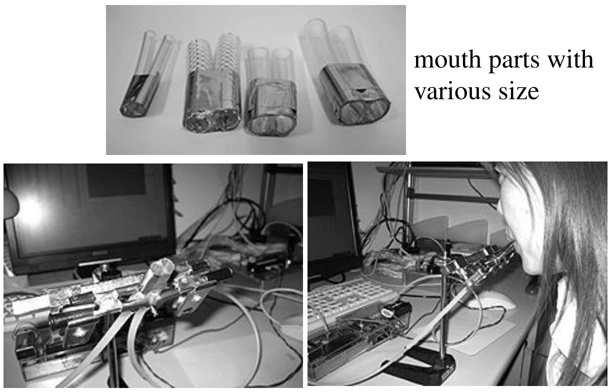

Fig. 13. Two-DOF input device using breath pressure

pressure for right are added.

When we consider this breath pressure interface as an alternative of control stick of two-degrees-of-freedom real-time analog input device, impossibility of using II and IV region is a disadvantage. However, we can use two-dimensional input using only region I (or I and III). We thus examine the possibility of two-dimensional input using this adjacent two pipes type interface.

We made several types of mouth par for this two-dimensional breath pressure interface as shown in Fig.13. The adjacent two pipes are fixed for an input interface using breath pressure. Subjects regulate their breath pressure and move their mouth with a slight left and right motion. By presenting desired paths (a square and a circle), the subject traces the desired path by this breath pressure interface.

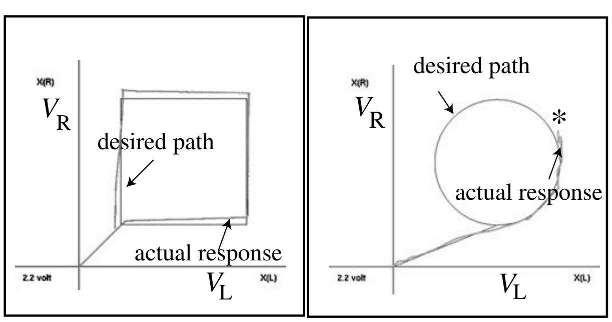

Fig. 14. Tracking ability for the 2-DOF input device

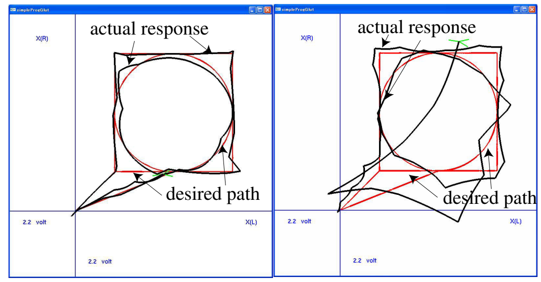

Fig. 15. Tracking ability for the improved input device

Figure 14 shows an example of the tracking experiment. Tracking the path of the square is realized by inputting positive pressure and negative pressure for two pipes. However, tracking circle is impossible at the point of * in the figure, because positive pressure for right pipe and negative pressure for left pipe is needed. But this is impossible using this device and the method of integrating breath pressure.

Then, we use left pipe' pressure as an input of direct command of angular velocity of wheelchair and integrated value of right pipe's pressure as an input of forward velocity. By this method, when users leave their mouth from the two pipes for normal ventilation, the current velocity maintains with forward direction (no rotation). We use strong negative pressure (over -1.7Kpa) for both two pipes as the command of emergency stop for safety. An example actual response by this method is shown in Fig.15, where a circle and a square is displayed as desired trajectory.

Left one of Fig.15 shows the case that a subject independently regulates breath pressure for left pipe and right pipe using the method. And the right one shows the case that a subject regulates breath pressure for two pipes at the same time. It is found that the independent regulation method takes more time than the case of simultaneous regulation for two pipes. Better tracking performance was obtained by the independent regulation method for two pipes.

By the basic performance experiment using two degrees-of-freedom input device of breath pressure, we conclude that the method can be used as an human interface to operate powered wheelchair. We then simulate the operation of powered wheelchair using the breath pressure interface. In this simulation, the velocity command for left and right wheels of powered wheelchair (ω_L and ω_R) are calculated by the following kinematics equation and control law.

$$\begin{pmatrix} \omega_L \\ \omega_R \end{pmatrix} = \begin{pmatrix} \frac{r}{2} & \frac{r}{2} \\ \frac{r}{l} & -\frac{r}{l} \end{pmatrix}^{-1} \begin{pmatrix} v \\ \dot{\theta} \end{pmatrix} \quad (2)$$

$$v = k_v \int_0^t g(p_R(t) - p_0)dt \quad (3)$$

$$\dot{\theta} = k_\omega p_L(t) \quad (4)$$

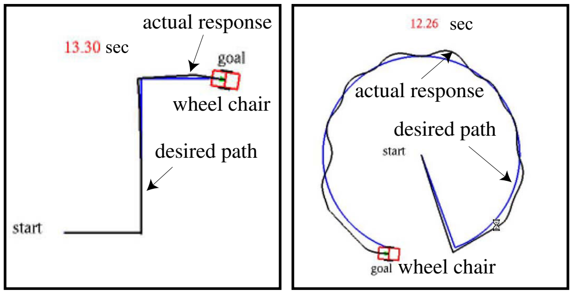

Fig. 16. Path of wheelchair by breath pressure control

Fig. 17. Control experiment of wheelchair by breath pressure

$$(p_R(t) < -p_{\max} \text{ then } v = 0)$$

where $p_L(t)$, $p_R(t)$ are expiration pressure value for left pipe and right pipe, r, l are radius of wheel and distance of the axle for the wheelchair, v, $\dot{\theta}$ are forward velocity and angular velocity of the wheelchair. The function of $g()$ is used to eliminate pressure noise, which is defined by (1). For a safety, strong negative breath pressure for both pipes generates the command of emergency stop of the powered wheelchair.

Using this control law, and combining actual two-degrees-of-freedom input device by breath pressure and numerical simulation of wheelchair's kinematics, trajectory tracking experiment is tested.

One of the results is show in Fig.16, where left figure shows a response of tracking for a crank path and right figure shows a response for a circle path. The experiment is done by using an actual breath pressure input device and kinematics simulation of a wheelchair. By this result, it is found the wheelchair tracks the desired straight line very nicely, however there are small deviation for the tracking of circle.

IV. CONCLUSION

This paper proposes a new human interface for the severely handicapped using their breath pressure. Control of powered wheelchair is tested using the interface method. The followings are summary of the study.

- Using a one-degree-of-freedom input device by breath pressure, step response for unpredictable desired pulse is experimented. In the experiment, integrated value of breath pressure is used instead of direct breath pressure. The result shows that the proposed interface method has almost same performance with the case of control stick. Especially, it is found that human regulation ability of expiration (positive breath pressure) is better than the ability of inspiration (negative breath pressure).
- The characteristics of frequency response for the input method by integrated breath pressure is examined. Then it is found that the proposed input method has almost same performance with the performance by control stick. A method for selecting the optimum integral constant is also presented, based on the performance experiment.
- Considering the use of the breath pressure interface method for an operation of powered wheelchair, two-degrees-of-freedom interface method by the breath pressure is discussed. By setting left pipe's pressure as an input of direct command for angular velocity and setting integrated value of right pipe's pressure as an input for forward velocity of wheelchair, it is shown that the breath pressure input interface can be used as an input interface to control powered wheelchair, by stimulational experiment using actual breath pressure interface device.

We are currently doing experiments using actual powered wheelchair by the proposed two-dimensional breath pressure analog input interface method as shown in Fig.17. Detailed results will be reported near future.

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