3D Head Pointer : A manipulation method that enables the spatial localization for a wearable robot arm by head bobbing

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***Abstract*— This paper introduces a new type of interface "3D Head Pointer" for operation of a wearable robot arm in 3D space. The developed system is aimed at assisting the user in execution of daily chores (e.g. opening an umbrella, stirring a pot) while concurrently operating wearable robot arm. Previous researches have demonstrated the difficulty in simultaneously controlling a robot arm while uninterruptedly performing another task with one's own hands. The proposed method uses a combination of the orientation of the face and head bobbing (a forward and backward movement of the head) to manipulate spatial localization in a polar coordinate system. In a Virtual Reality (VR) environment, the proposed system and its efficiency at adapting its operating magnification (IDF) by relying on the incremental changes in head bobbing were evaluated through measurement of the instructional accuracy and time demand. Experiments were conducted with 12 participants. Results displayed an accuracy of 1.3 cm with a 4 seconds time span necessary to communicate an instruction. These results, along with the confirmed ability of an individual to multi-task while operating, suggested the effectiveness of the operation method and IDF.**

Keywords*— *VR/AR, Hands-free interface, Polar coordinate system, Teleoperation

I. INTRODUCTION

In recent years, there has been a lot of research and development on the use of Supernumerary Robotic Limbs (SRL) for "body enhancement". In the past, robotic technology, especially wearable robotics, was developed as protheses or for rehabilitation purposes. SRL aims to provide its users with additional capacities, enabling them to accomplish tasks that a person alone would otherwise not be capable of. In this respect, SRL is very different from other types of existing wearable robots. One of the most recent examples is the lightweight, yet sufficiently torquey and highly maneuverable SRL developed by Veronneau [1]. Such robotics are aimed at being used in any context, helping individuals perform both household chores, and improving industrial productivity.

To effectively assist in daily chores (opening an umbrella, stirring a pot, etc.), users require an interface for them to indicate the target point location to SRL's end effector without requiring him/her to interrupt his/her actions. However, a method to do so has not yet been established. Parietti [2][3] developed a manipulation technique in which the operator's movements were monitored on the robot side and the robot arm performed movements according to the work state. Iwasaki [4] proposed an interface that allowed the operator to actively control SRL by using the orientation of the face. Furthermore, Sasaki [5] showed a manipulation method that enabled more complicated operation of the robot arm by using the user's own legs as a controller.

Previous studies have overlooked the balance between ensuring motion freedom of the operator's limbs and giving detailed instructions to the SRL. There are still challenges in multi-tasking in a daily life context. Therefore, in this study, the authors propose a method for manipulating SRLs, so that two parallel tasks do not interfere with each other, and evaluated its usefulness.

II. INTERFACE FOR SRL

In this section, the requirements for achieving daily support for parallel work are described. The following two elements were considered to be essential:

1) Does not affect the movement of the operator's limbs

2) Spatial localization can be indicated

Several hands-free interfaces have been proposed to satisfy (1). Some of them are operated by the tongue [6], eye movement [7] and voice [8], these methods are used for either screen control or robot manipulation (or both). Methods to control robotic limbs with brain waves [9] are also being investigated.

However, this study focuses on requirement (2) and constructing a more intuitive instructional method. When giving directions in relation to a 3D space location, it is necessary for the operator to accurately indicate the target point. The range of the field of view within which a person can perceive the shape and position of an object is as narrow as 15 degrees from the point of gaze [10]. Hence, a compensatory action of directing the face and gaze in the instructional space is necessary for spatial localization instructions. Therefore, this interface takes advantage of the compensatory action of turning the face and uses it as an instruction method.

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Methods for using the head as a joystick have already been proposed. One of which is to manipulate the head for instruction to a 2D plane, such as on-screen operations [11]. The other method is to switch between the vertical and horizontal planes by nodding to the plane to be manipulated. This supplements the plane manipulation by the head, so that only the head is used to manage the 3D space [12]. However, these methods do not use compensatory motion of the head as a manipulation technique.

III. MANIPULATION METHOD USING HEAD BOBBING AND GRADUAL CHANGE OF DEPTH FACTOR

The motion of turning one's face can be used to instruct the radial direction of the target point, in the polar coordinates. Fig. 1 shows an image of the operation using Unity-Chan (humanoid model created by Unity Technologies Japan [13]).

Fig. 1. Image of the operation in the direction of the face

In this paper, we propose a 3D Head Pointer, a pointing interface that combines head bobbing with the orientation of the face in a polar coordinate system. Head bobbing is a combination of small back and forth motion of the head that does not interfere with the operator's movement.

This study was performed using, as reference, the standard morphology a Japanese man, as recorded by Kouchi [14]. According to this data, the range of head bobbing was determined to be about 9.29 cm, a range which allows the operator to keep the zero-moment point in the torso of the body and operate a robot arm without losing his balance. A doughnut shaped area setting with innermost radius of 30 cm and outermost radius of 100 cm around the operator was defined as an example of an SRL operating range [15]. The depth change factor by head bobbing was 70/9.29 = 7.53 or more. The range of motion which can be performed using Head bobbing is inferior to that of one's arms. Hence preliminary experiments showed that at high magnification, the instruction accuracy of the head bobbing was lower than comparable methods. Additionally, the required for instruction was shown to be longer. Therefore, an Increase/Decrease Factor (IDF) that changes the depth of the head bobbing in a stepwise manner according to the head velocity was introduced. The IDF allows for precise instructions while maintaining high magnification. In this study, the IDF was constructed using the mouse cursor change factor showed in Fig. 2 set by Microsoft Windows [16].

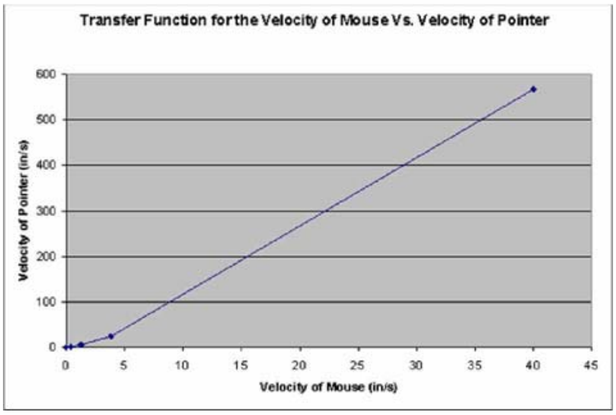


Fig. 2. Microsoft's mouse cursor speed change settings[16]

IV. EVALUATION OF THE USEFULNESS OF THE PROPOSED METHOD

This section examines the usefulness of the IDF and the 3D Head Pointer as a whole.

This study was done while considering the previously developed robot arm proposed by Nakabayashi [15] and Amano [17], shown in Fig. 3.

Fig. 3. External view of the robotic arm in the previous study

The arm has a reach of up to 1 m, and its jamming hand shown in Fig. 4 can be used as an end-effector to grasp an object with an error of up to 3 cm [17]. Hence, the allowable indication error at the interface in this experiment is set within 3 cm.

Fig. 4. External view of the jamming hand

In this study, validation was done in a VR environment. Indication of radial direction by face orientation was measured from the front of the Head-mounted Display (HMD). The depth indicator was implemented by setting up a sphere with the operator at the center as shown in Fig. 5, and changing the radius of the sphere by head bobbing.

Fig. 5. 3D Head Pointer Operation image

User can experience the proposed method using an HMD (HTC VIVE [18]). The experimental procedure is described hereafter.

1) The participant wears the VIVE headset, holds a VIVE controller in each hand and holds them up in front of his or her chest, as shown in Fig. 6 right image. This is defined as the "rest position". The subject's avatar is displayed in the VR space, as shown in Fig. 6 left image.

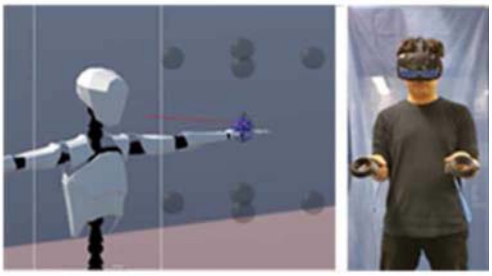


Fig. 6. Experiments constitution for the interface operation (left : instructional goals and participants within the VR ; right : participant wear HMD and controller)

2) The 3D Head Pointer's control cursor (the red ball in the center of Fig. 6) appears 65 cm in front of the eye. Simultaneously, a 10 cm-diameter target sphere (the blue transparent sphere in the upper right corner of Fig. 7) appears at any of the 8 locations at ±30 cm in height, ±20 cm in width, ±20 cm in depth, ±20 cm from the cursor's position.

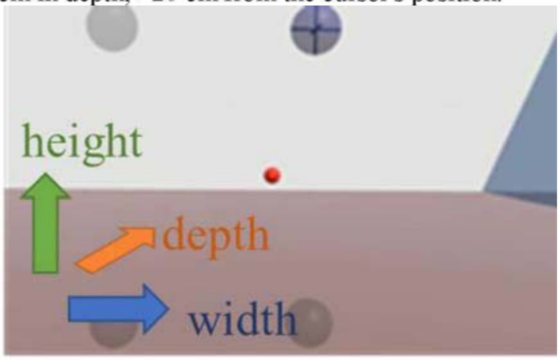


Fig. 7. Subjective view of the subject's operation

3) The participant aligns the cursor to the center of the target sphere using the 3D Head Pointer.

4) When the participant thinks having reached the center of the target sphere, he/she gives a signal by speaking out. The instruction is considered as being completed. As shown in Fig. 8, the target sphere has a reference frame with its origin at the center of the sphere. The participant adjusts the position of the cursor based on it.

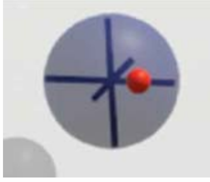


Fig. 8. Target sphere and cursor visibility

5) Steps (1) to (4) are performed for all 8 target sphere positions.

The above procedure was performed by two groups of 6 participants each. Experiments were performed several times under different conditions for each group. Table1 shows the experimental conditions and the group distribution. Group 1 was made to perform the same tasks as described but with a predefined time limit for the instruction execution. Group 2 was made to perform the experiment either with or without IDF.

TABLE 1. TARGET SPHERE AND CURSOR VISIBILITY

	Requirement	**Group**
a	No requirements	1, 2
b	2 seconds time limit for instruction	1
c	3 seconds time limit for instruction	1
d	4 seconds time limit for instruction	1
e	6 seconds time limit for instruction	1
f	8 seconds time limit for instruction	1
g	the rate of change in depth due to head bobbing is fixed at 10 times	2

Fig. 9 shows the relationship between Head bobbing speed and magnification. The "Not available IDF" is a condition in which the rate of change in depth due to head bobbing is fixed at 10 times without using the IDF.

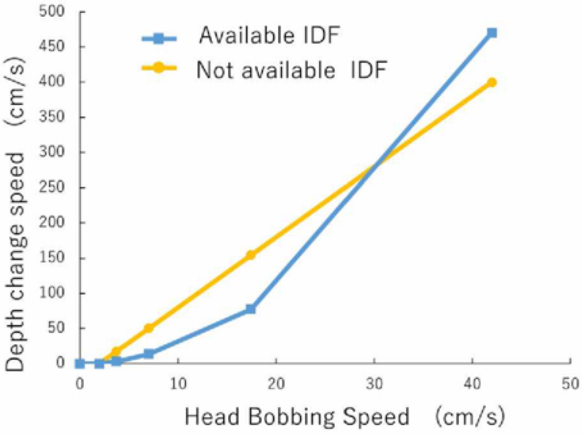


Fig. 9. Change in head bobbing magnification with and without IDF

Based on the aforementioned experiments, the usefulness of the 3D Head Pointer as a whole was evaluated using the average indication error condition in (a), the relationship between the indication accuracy error and the operation time in (a)~(f), and the maximum arm sway of the subject measured by the VIVE controller in (a).

At the same time, the usefulness of the IDF was tested by comparing the instructional error between conditions (a) and (g).

V. Results and Discussion

In this study, the Wilcoxon signed sum rank test was used to verify the significant difference between any two conditions. The Wilcoxon signed rank sum test is a type of non-parametric test used when the distribution of the population does not follow a normal distribution. We obtain the difference $Zi = Yi - Xi$ for experimental values for two conditions Xi, Yi performed on the i-th participant. Next, we arrange the Zi in order of decreasing absolute value, and assign the rank Ri to the smaller one. The Wilcoxon sign sum rank test quantity $W+$ is then

$$W^{+} = \sum_{i=1}^{n} \emptyset_i R_i \tag{1}$$

But in this case, $\emptyset i$ is calculated by

$$\emptyset_i = \begin{cases} 1(Z_i > 0) \\ 0(Z_i < 0) \end{cases} \tag{3}$$

Significant differences are calculated by comparing the above test quantity W to the table of numbers[19]. In this experiment, Excel statistics was used to calculate significant differences instead of number tables.

A. Indication Error

The instructional error from the distance from the center of the target ball to the control cursor was measured upon instruction completion. This was done in VR using an IDF-based 3D head pointer for 12 people in divided into two groups (1 and 2). Results are shown in Table2.

TABLE 2. AVERAGE INSTRUCTION ERROR

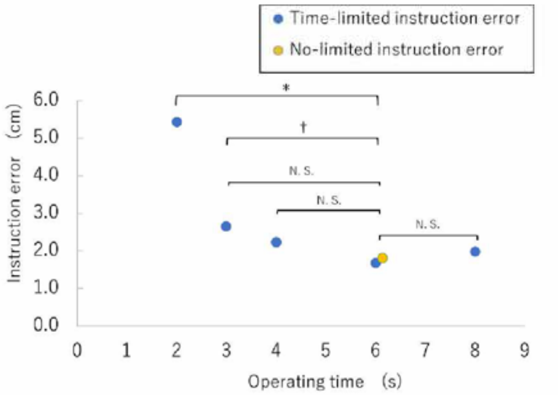
Subject	Instructional error (cm)
1	1.20
2	2.50
3	1.54
4	2.19
5	2.41
6	1.06
7	1.06
8	0.882
9	0.757
10	0.905
11	0.695
12	0.668
Average	1.32

The end effector used as reference index this study was a jamming hand [17] capable of grasping an object with an error in target point indication of up to 3 cm. The average error of the instructions in this experiment was of about 1.32 cm, with the highest instructional error being of 2.5 cm. These results suggest that the indication error of the 3D Head Pointer is within the range of absorbable error in the case of grasping and manipulating an object with that specific end effector.

The standard deviation of the indication error is 0.65 cm, with the error varying widely from person to person. This result may be related to the familiarity level of each individual to the use of a VR space. There is a need to validate the results by considering the VR experience.

B. Change in indication error at each indication time

The experiment was conducted under conditions (a)-(f) for six members of group 1. The relationship between instruction error and instruction time is shown in Fig. 10.



(Wilcoxon signed-rank , N=6, *:p<0.05, , †:p<0.1, N.S:not significant)

Fig. 10. Instruction error per operating time in the evaluation test

The average operation time under condition (a) (no time limit) was 6.2 s. When the operation time was limited, the indication error decreased rapidly as time limit increases from 2 to 3 seconds. When the time was superior to 4 seconds, this error remained almost constant, regardless of the time taken. This suggests that the operation with the 3D Head Pointer itself was already completed by the 4 seconds.

C. Maximum arm sway

For the six participants in group 1, his/her maximum arm sway was measured from the movement of the VIVE controller with standing upright only, and compared to the maximum arm sway when the 3D Head Pointer was manipulated in condition (a). The results are shown in Fig. 11.

(Wilcoxon signed-rank ,N=6, †:p<0.1)

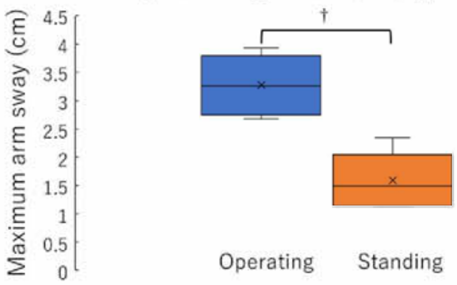


Fig. 11. Maximum arm sway when standing and operating

Maximum arm sway tends to be greater with a 3D head pointer than with just standing. However, the Wilcoxon sign-sum rank test doesn't show any significant difference in these two conditions (N=6, p<0.1), which suggests that the proposed method allows a user to continue performing regular arm motion while performing instruction indication. Because the proposed method requires visibility of the target space in order to perform tasks with SRL, multi-tasking is sometimes impossible and interruption of the task being performed by the user is unavoidable. However, if the operator's hand position can be maintained while using the 3D head pointer, the interrupted task can be resumed quickly after instructions to the SRL, which is likely to be significantly more efficient than performing the two tasks separately.

D. Differences in Indication Error with and without IDF

We conducted the experiment under conditions (a) and (g) for six members of group 2 and measured the instruction errors of the 3D Head Pointer and the depth-only instruction errors of Head Bobbing. The results are shown in Fig. 12 and 13, respectively. The use of IDF reduced the average instruction error by about 77.6% for the depth instruction by Head Bobbing and about 67.0% for total error in three axes (x, y, z). Additionally, the significant difference between the two conditions with and without IDF appeared in the Wilcoxon signed sum rank test (N=6, $p<0.05$). Therefore, it was confirmed that the introduction of the IDF greatly improved the accuracy and demonstrated its usefulness. Nevertheless, there still is a need to verify whether the accuracy can be further improved, with additional finetuning of parameters related to the magnification change ratio.

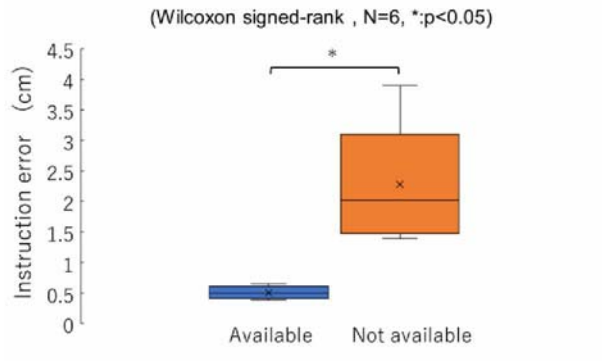


Fig. 12. Depth error by head bobbing with and without IDF

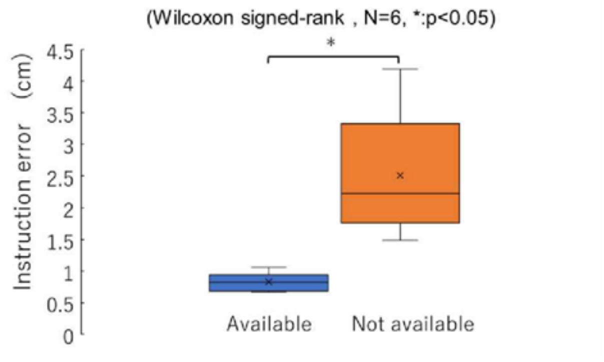


Fig. 13. Total error in three axes by 3D head pointer with and without IDF

E. Comparison with Other Similar Methods

Based on the results of results A~D, a comparison with other similar methods was made.

1) physical controller

Some SRLs, such as the one made by Vernonia [1], use a physical controller which is like gamepad with analog stick and some buttons as the method of operation. The advantage of the 3D Head Pointer is that its operation is more intuitive and easier to understand than that of a physical controller, and it can be operated hands-free. On the other hand, the 3D Head pointer is not designed for on/off operations such as mode switching. Therefore, a combination with other interfaces such as voice recognition will be necessary for hands-free, detailed input.

2) SRL manipulation method by foot

The proposed method can operate the SRL in any standing or seated position., compared to operating by legs [5]. However, leg manipulation can indicate not only the position of the SRL, but also its posture. How to direct the posture of the SRL is one of the problems of this proposed method.

3) Head Joystick and Nodding to Switch between the vertical and horizontal planes

Because the 3D Head Pointer uses compensatory motion of the head, it is less operational burden than methods that use the head as a joystick [11][12]. On the other hand, the nodding method [12] allows for digital input from the head alone and may be used in conjunction with the 3D Head Pointer.

Based on the above comparison, how to add SRL posture and digital instructions to the 3D Head pointer needs to be considered in combination with other similar methods.

F. Limitation

In evaluation test in the previous section, the depth of the randomly appearing target sphere was at two locations between 65 cm and ±20 cm in front of the operator. Fig. 14 shows the indication accuracy for each distance when indicating spatial orientation.

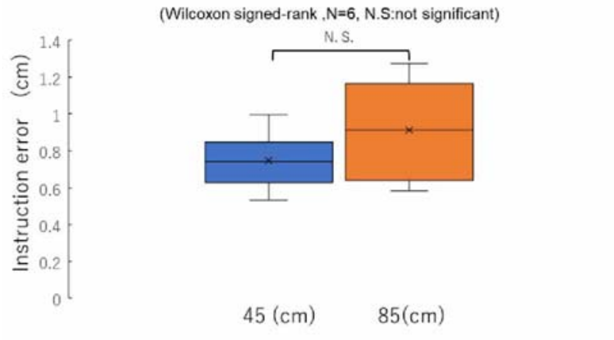


Fig. 14. Instruction error between target sphere distances

Although there is no significant difference by the Wilcoxon sign-sum rank test (N=6, not significant), it can be seen that the variation in accuracy becomes larger as the distance to the target point increases (from 45cm to 85cm). This may be due to decreasing in visual information as the target becomes more distant. In this experiment, the radius of one meter, which is the working range of SRL, was set as the operating range. However, if the 3D Head Pointer is used to instruct a wider range of operations than the SRL, the instructional error may be larger than in this experiment. The improvement of this is one of the major issues, and it is necessary to verify the improvement of accuracy by combining it with other factors, such as line of sight.

VI. CONCLUSION

In this study, we proposed a spatial localization instruction Interface for SRLs to improve work efficiency in daily life chores execution. The presented system addresses the issue of the need for a method to provide localization instructions in space. The required functions for indicating spatial orientation were described , and a 3D head pointer interface that combined the head-bobbing depth indicator and the polar coordinate system based on the orientation of the face was conceived. In addition, the IDF was introduced to improve the operability of the depth indicator. In a VR environment, evaluation tests of the 3D Head Pointer and the IDF were conducted. Results displayed that the 3D Head Pointer was able to indicate with sufficient accuracy without requiring him/her to interrupt his/her actions. Additionally, the introduction of an IDF greatly improved the accuracy of the 3D Head Pointer. The results provided useful knowledge for improving the SRL interface.

As future work, we will verify instructions to SRL in real space using AR glasses and the actual SRL assumed in this experiment [15]. Additionally, we would like to use this technology not only for SRL, but also for remote control of robots and drone control.

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REFERENCES

[1] C. Veronneau, J. Denis, L. Lebel, M. Denninger, V. Blanchard, A. Girard, J. Plante, “Multifunctional 3-DOF Wearable Supernumerary Robotic Arm Based on Magnetorheological Clutches” IEEE Robotics and Automation Letters, Vol. 5, Issue 2, pp.2546-2553, 2020.

[2] C. D. Parietti, H. H. Asada, “Design And Biomechanical Analysis Of Pernumerary Robotic Limbs”, Proc.IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2012.

[3] H. H. Asada, F. Parietti, “Supernumerary Robotic Limbs for Aircraft Fuselage Assembly : Body Stabilization and Guidance by Bracing”, Proc.IEEE/ICRA, pp119-125, 2014.

[4] Y. Iwasaki and H. Iwata, “Research on the Third Arm : proposal of a face vector interface for voluntary and intuitive control of a wearable robot arm”, IEEE/RSJ Int. Conf. Intell. Robot. Syst., 2017.

[5] T. Sasaki, M. Saraiji, K. Minamizawa, M. Inami, “MetaArmS: Body remapping using feet-controlled artificial arms”, UIST 2018 - Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology, pp.140-142, 2018.

[6] S. G. Terashima, J. Sakai, T. Ohira, H. Murakami, E. Satho, C. Matsuzawa, S. Sasaki, K. Ueki, “Development of a Tongue Operative Joystick - For Proposal of Development of an Integrated Tongue Operation Assistive System (I-to-AS) for Seriously Disabled People -”, The Society of Life Support Engineering, Vol.24, No.4, 2012.

[7] R. Barea, L. Boquete, M. Mazo, E. Lopez, “System for assisted mobility using eye movements based on electrooculography”, IEEE Trans Neural Syst Rehabil Eng, Vol. 10, Issue 20, pp.209-218, 2002.

[8] R. C. Simpson, S. P. Levine, “Voice control of a powered wheelchair”, IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol. 10, Issue 2, pp.122-125, 2002.

[9] S. Nishio, C. I. Penaloza, “BMI control of a third arm for multitasking,” Science Robotics Vol. 3, Issue 20, 2018.

[10] T. Miura, “Behavioral and visual attention”, Japan, CA:Kazama Shobo, 1996.

[11] R. Hasegawa, “Device For Input Via Head Motions”, Patents WO 2010/110411 Al, 2010.

[12] A. Jackowski, M. Gebhard, A. Gräser, “A novel head gesture based interface for hands-free control of a robot”, Proc.2016IEEE Int. Symp. Med.Meas. Appl. MeMeA , 2016.

[13] © Unity Technologies Japan/UCL, “Unity-chan!”, Available: https://unity-chan.com/, 2014.

[14] M. Kouchi, M. Mochimaru, “AIST Anthropometric Database”, National Institute of Advanced Industrial Science and Technology, H16PRO 287, 2005.

[15] L. Drohne, K. Nakabayashi, Y. Iwasaki, H. Iwata, “Design Consideration for Arm Mechanics and Attachment Positions of a Wearable Robot Arm”, Proc.IEEE / SICE International Symposium on System Integration (SII), pp.645-650, 2019.

[16] Windows Dev Center - Hardware, “Pointer Ballistics for Windows XP”, Available: http://archive.is/20120907165307/msdn.microsoft.com/en-us/windows/hardware/gg463319.aspx#selection-165.0-165.33, 2002.

[17] K. Amano, Y. Iwasaki, K. Nakabayashi, H. Iwata, “Development of a Three-Fingered Jamming Gripper for Corresponding to the Position Error and Shape Difference”, RoboSoft 2019, pp137-142, 2019.

[18] HTC VIVE, Available: https://www.vive.com/eu/product/vive/, 2011

[19] C. Zaiontz, “Wilcoxon Signed-Ranks Table”, Available: http://www.real-statistics.com/statistics-tables/wilcoxon-signed-ranks-table/, 2020.