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Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor Romy Budhi Widodo1, Reyna Marsya Quita2, Rhesdyan Wicaksono Setiawan1, Chikamune Wada3 1Informatics Engineering Study Program, Ma Chung University, Malang, 65151, Indonesia 2Department of Mathematics, Faculty of Science, National Central University, Taoyuan City, 32001, Taiwan 3Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Wakamatsu, Fukuoka, 808-0196, Japan Correspondence to: Romy Budhi Widodo (romy.budhi@machung.ac.id) Abstract. This paper works on the new study of hand orientation to be a substitute for the computer mouse movement, and is evaluated based on ISO/TS 9241 part 411: Ergonomics of human-system interaction standard. Two pairs of hand orientation candidates were evaluated, such as pitch-roll and pitch-yaw in substituting up-down and left-right mouse cursors' movements, as well as

a standard mouse as a baseline 1

comparison. The empirical study was conducted to evaluate quantitative performance such as throughput and movement time. The

performance test was **based on Fitts' test using a** multi **-direction tapping test** as suggested by **ISO/TS 9241-411.** 1

The test was broken down in some levels of difficulty such as

high, medium, low, and very **low.** In **the** 1

qualitative result, the assesment of comfort movement was conducted using comfort -rating scales to rate the movement candidate independently and comparatively. The result suggests that pitch-roll and pitch-yaw movement of the hand could be used as a substitute for the mouse with the throughput among those candidates not statistically difference. The throughput of pitch-yaw is slightly higher than for the pitch-roll candidate, as well as the movement time in pitch-yaw being slightly faster than in pitch-roll. We also found that pitch-yaw movements have a higher level of comfort based on the comfort - rating scale test. The other results explain that orientation movement was suitable only for the task with a low and very low level of difficulty. This study provides a new suggestion of a suitable level of

difficulty when using an inertial sensor as an emulator for the movement of a mouse cursor in the field of human-computer interaction. 1 Introduction A computer mouse's main function is as a pointing device for the userto navigate,target, and command execution through 25 mouse movement and button-clicked action (Lazar, Jonathan; Feng, Jinjuan Heidi; Hochheiser, 2017) and (Natapov et al., 2009). The mouse as a pointing device could not be used for someone who is disabled due to some certain reasons: 1) The fingers' impairment caused by a malfunction of the sensoric system and congenital disorder; 2) The person has difficulty operating a computer in a sitting position. Therefore, a study of the suitable hand gestures or hand movement or hand orientation which serve as a substitute for a conventional mouse is needed. Some research found that a mouse replacement could be categorized into some groups,as an example handglove,grasping, and optic type. The material used in the handglove type using an acceleration sensor was introduced in (Perng, J.K.; Fisher, B.; Hollar, S.; Pister, 2002), an acceleration sensorwas also used in edutainment as a control (Kranz et al., 2010); fiberoptic in (Zimmerman et al., 1986); flexible plastic resistive ink sensoras in Power Glove by Mattel, Inc., (Sturman, D.J.; Zeltzer, 1994); and ultrasonic and magnetic hand position tracking technology as in Data Glove (Zimmerman et al., 1986) and (Zimmerman, Thomas G.; Lanier, 1989). The grasping type as in a Wii remote, GyroPoint, and RemotePoint was discussed and studied in (Natapov et al., 2009), (MacKenzie and Jusoh,2001), and (Norman and Norman, 2010). The use of optic type such as a

laser pointer as a pointing device have been **discussed in** 1

(Myers et al., 2002) and (Oh and Stuerzlinger, 2002). Much of the current literature on pointing devices pays particular attention to others evaluating and comparing pointing devices; 10 however the investigation of gestures has not been highlighted in those studies . One of the most significant parts that can be used to emulate the movement of a mouse is limbs, due to its ability in multi - direction movement. The wrist movement in the tri-axial plane, such as the frontal, median, and transverse plane represent the orientation of roll, pitch, and yaw, respectively. The wrist movement consists offlexion-extension and radial-ulnar deviation; the forearm movement consist of forearm pronation and forearm supination as in (Gates et al., 2016) and (Nelson D.L.; 15 Mitchell M.A.; Groszewski P.G.; Pennick S.L.; Manske P.R., 1994). In this paperwe relate those movements to the orientation axis, in which flexion-extension represents pitch, pronation-supination represents roll, and radial-ulnar deviation represents yaw. Figure 1 illustrates the wrist and forearm movement. The range of motion related to these movements reported in (Gates et al., 2016) and (Nelson D.L.; Mitchell M.A.; Groszewski P.G.; Pennick S.L.; Manske P.R., 1994) for wrist flexion and extension is: 38o and 40o; wrist radial and ulnar deviation: 28o and 38o; and forearm pronation and supination: 13o and 53o. Inspired by (Perng, J.K.; Fisher, B.; Hollar, S.; Pister, 2002), (Zimmerman et al., 1986), (Sturman, D.J.; Zeltzer, 1994), (Zimmerman, Thomas G.; Lanier, 1989) and evaluated by (Natapov et al., 2009), (MacKenzie and Jusoh,2001), (Norman and Norman, 2010), (MacKenzie et al., 2001), and (Widodo and Matsumaru, 2013), this study set out to clarify several aspects of the two candidates of movement gestures: pitch-roll and pitch-yaw, to substitute the movement of the mouse cursor. We worked on comparing the performance of pitch-roll and pitch-yaw quantitatively and qualitatively based on ISO 9241

part 411: 25 **evaluation methods for the design of** physicalinput **devices.** 1

The rest of the paper is organized as follows: Section 2 discusses ISO/TS 9241 related to evaluation procedure and Fitts' formula, section 3 discusses research methodology; section 4 presents the experiment results and section 5 elaborates on the results to be a discussion.Lastly, section 6 presents the conclusion of the study. 2 ISO/TS 9241-411 30 ISO 9241 is a standard used for human-systeminteraction (International Organization for Standardization, 2012). ISO 9241

part 411 (ISO/TS 9241-411) discusses the **evaluation methods for the design of physical input devices.** 1

The quantitative assessment of performance was measured by throughput and movement time,

as well as using a comfort -rating scale to assess comfort 1

qualitatively. The dependent measure of Throughput (TP) defined in ISO was based on Fitts' law model. Fitts' law proposed an index of difficulty of a movement based on the relationship between distance (amplitude), movement time (duration), and distance variability. The TP is the index of difficulty (ID) divided by movement time (tm) (Fitts, 1954) and (Mackenzie, 2018). Based on the Shannon-Hartley theorem, the formulation of the ID is in (1): 5 ID ? log2 d ? w w (bit) , (1)

where d is the distance of movement, and w is **the target** width. **The** 1

ISO procedure includes the four levels of difficulty (ID), such as high (ID > 6); medium (4 < ID ≤ 6); low (3 < ID ≤ 4); and very low (ID ≤ 3). The tapping coordinates to a user spreading around the target's center. Therefore, the scatter data should be used to adjust the accuracy of each user as suggested in (Mackenzie, 2018). The ISO standard dependent measurement, throughput, was 10 calculated using this adjustment for accuracy. The equation (1) was modified to be in (2): IDe ? log 2 d ? we ; we ? 4.133.sx we (2) TP ? IDe tm (3) 15 20 where we is the effective target width and sx is the standard deviation of the clicked target's coordinate. The movement time (tm) was calculated from one target to the other target in seconds. Finally, the TP is the effective index of difficulty (IDe) divided by tm results in bits per second (bps). The one direction tapping task as in (Fitts, 1954) does not concern the angle of movement in the performance assessment; therefore ISO 9241-411 recommends a multi-direction tapping task. The evaluation using the multi-direction tapping task was used in (Norman and Norman, 2010), (MacKenzie et al., 2001), and (Douglas et al., 1999). The pattern of multi-directio n tapping task is illustrated in Fig. 2. The target consists of twenty-five small circles, which are tapped sequentially according to the number or color changes as illustrated in Fig. 2(a). The actual clicked target in each small circle is the centre of coordinates of the circles; however, spreading tapping by each subject in each experiment caused the effective target and standard deviation (sx). Figure 2(b) illustrates a spreading tapping coordinates by each subject, symbolized by x, spread around the centre of circle (xc,yc). Every clicked coordinate out of the circle will be recognized as an error. In the beginning, the IDe in equation (2) reserved for one-direction tapping task;

the IDe for multi-direction tapping task was calculated based on the extended of equation (2) as in (Norman and Norman, 2010) and (International Organization for Standardization, 2012). For the calculation conducted in each small circle, all clicked coordinates are analyzed relative to (xc, yc) and finally will be averaged. Equation (4) calculates the mean of the clicked coordinates, then in (5) the subtraction for each x and y coordinate. X?N?i?1xi; Y?N?i?1yi 1 N 1 N (4) xˆ?xi ?X ; yˆ?yi ?Y (5) 5 The two dimension standard deviation as in (6). s x ? N1 ?iN?1 d i2 (6) The distance d is formulated as in (7). di2 ? xˆ2 ? yˆ2 (7) 10 The calculation of the effective target width (we) as in (2), rewritten in (8). The effective index of difficulty is written in (9). we ?4.133.sx (8) IDe ?log2??we ? d ?1? ? ? (9) Finally, the throughput (TP) as in (3) is rewritten in (10) as the performance value of the device. TP ? IDe tm (10) 3 ISO/TS 9241-411 3.1 Participants 20 Nineteen right-handed subjects, fifteen males and four females,

who were an average of 27.1 **years old, standard**	1

deviation (SD) = 6.2 were recruited from university students and staffs. All subjects were informed about the procedure before the experiment began. 3.2 Experiment Design The experiment was conducted using a within-subject experimental design. The learning effect was reduced by two ways: 1) 25 randomizing the order of experiment based on index of difficulty level (ID level), and 2) conducting a sufficient session for practice until the subject could get used to operating the evaluation software and experimental apparatus. Every subject used two devices: a standard mouse and inertial sensor. The inertial sensor was used in two ways: pitch-roll and pitch-yaw gestures; therefore, in this paper we treated the sensor as two devices; the total number of devices was three, including the standard mouse. There are four levels of difficulty: 1) mode 1 is very low level of difficulty; 2) mode 2 is low level of difficulty; 3) mode 3 is medium level of difficulty; and 4) mode 4 is high level of difficulty.

Table I describes the design of ID **levels using**	1

a computer display resolution of 1280 x 1024 pixels; the d and w indicate the distance of movement and target width, respectively (see Fig. 2a). The number of blocks are three and three trials per block. Therefore, for nineteen subjects, the

design is 19 **x 3 x 4 x** 3 **x** 3; **the number of trials was**	1

2,052. 3.3 Apparatus/materials 10 The experiments used 3 DOF tracking InertiaCube 4™ to record the orientation angle such as pitch, roll, and yaw. The manufacturer’s accuracy specification: 1o in yaw, 0.25o in pitch, and roll at 25oC. The other input device is a standard mouse (Microsoft® Basic Optical Mouse v2.0) as a baseline condition. The C# software was developed to record orientation data, emulate the mouse cursor movement using the orientation angle data, and display the multi-direction tapping task simultaneously. Software specification was designed to fulfil the Annex B of ISO/TS 9241-411 which consists of: 1) four 15 levels of difficulty; 2) movement time recording, 3) clicked coordinate recording, and 4) an error count indicator, which is accompanied by sound feedback when a subject clicks an area outside the target. The qualitative assessment of comfort and fatigue was conducted using the comfort rating scale questionnaire and rating of perceived exertion (RPE), as suggested by

Annex C of ISO/TS 9241-411. 3.4 **Procedure**	1

25 30 The illustration of the systemis illustrated in Fig. 3. A subject sits about 0.9 m from the display, the forearm resting on the chair armrest when using the 3 DOF sensor for testing. However, the hand is normally on the desk when operating a mouse test.The 3 DOF tracking sensorwas mounted on the back of the dominant hand,which is the middle part of the dorsalsurface. The right and left mouse click event were the same for all levels of test.Subjects used a conventionalmouse grasped with the dominant hand as the click part by employ the mouse left-button. The PC monitor displays the multi-direction tapping task. The sound speaker gives a warning when the subject misses the target; the sound speaker is not shown in the figure. Figure 4 illustrates the orientation of axes of the sensor; θy (pitch), θx (roll) , and θz (yaw) are the rotation angles about y, x, and, z-axis , respectively. Figure 4 also describes the mapping for a sensorand cursor. Before the experiment began, the purpose and experiment procedure was explained to every subject. Also, the subject practiced the task until the speed did not show any improvement. The sequence of index of difficulty level was randomized, as well as the sequence ofthe devices.The multi-direction tapping is a point and click task, and each session consists oftwenty- five clicked targets. The movement time was recorded starting when they clicked the first target until they clicked the last, as well as the clicked coordinates and the number of errors. For “pitch-roll” gesture,a subject moved his wrist flexion-extension 5 and forearm pronation-supination. The “pitch-yaw” gesture is a movement of wrist flexion-extension and radial-ulnar deviation. 4 Experiment Results 4.1 Throughput (TP) and Movement Time (tm) 5 Throughput

provides a measurement of speed and accuracy. The summary **of**	1

the results include error rate in Table II presents in “mean (standard deviation).” The result of error rate comes from the average number of errors of all blocks and modes for nineteen subjects. Basic descriptive statistics were conducted; deviation from the normal distribution or tests of normality were conducted using the Shapiro-Wilk test; the null-hypothesis is the data from a normally-distributed population. Figure 5 describes the 10 boxplot of all data distribution related to throughput and movement time. The Shapiro-Wilk testing for normality indicated that the TP was normally distributed for the mouse, pitch-roll, and pitch- yaw device group ($p>0.05$). Next, the test of homogeneity of variances using Levene’s test yields signifance at $p=0.025$, meaning that variances of TP’s categories in devices are not equal. The assumption of homogeneity of variances is not met. The Welch-ANOVA was used to understand whether there is a difference in mean of throughput value in all devices. The null 15 hypothesis:all TP value means are equal (i.e., μTP mouse = μTP Pitch-Roll = μTP Pitch-Yaw). The alternative hypothesis (HA) is at least one category mean is different. The Games-Howell post hoc test shows that the multiple comparison table revealed that there are statistically significant differences between the Mouse and the two other devices (p < 0.05), but there is no statistically significant difference between 1

Pitch-Roll and Pitch-Yaw. The test for tm indicates that Pitch-Yaw is p=0.046, suggesting evidence of non-normality. The independent Kruskal-Wallis 20 test is summarized as follows: the mean ranks of tm values were statistically significantly difference between categories, ($\chi 2(2) = 23.473$, $p = 0.0005$). The Mann Whitney U post-hoc test using multiple comparisons was conducted to interpret all pairwise comparisons. The results indicate that the tm in Pitch-Roll category was not statistically higher than in the Pitch-Yaw ($U = 63$, $p = 0.603$). However, the tm in Pitch-Roll category is significantly higher than in Mouse ($U = 0.0005$, $p = 0.0005$) and the tm in Pitch-Yaw category is also significantly higher than in Mouse ($U = 0.0005$, $p = 0.0005$). 25 To deeply analyze the influence of index of difficulty (mode), the dependent-t test was conducted to compare the means between each mode on TP and tm. The dependent variable is the value of TP and tm, while the independent variable is the same subject present on two occasions on the same dependent variable. Table III concludes the results of significance levels of each pair. We could see that in all devices, mode 3 and mode 4 has statistically significantly difference result. Mode 4 is the mo st difficult mode, which causes the difference. 4.2 Error Rate The percentage of clicked coordinates outside the target was calculated and the average is shown in Table II. Figure 6 shows the graph of error rate using mode as a repetition. The error rate is related to the index of difficulties; as previously mentioned, mode 1 is the lowest level of difficulty and mode 4 is the highest level of difficulty. Therefore, as expected, the error rat e of mode 4 is the highest. As shown in Fig. 6, the error rate of modes 3 and 4 of the sensor's gestures is far above the error rate of the mouse. The error increment from mode 2 to 3 at Pitch-Roll and Pitch-Yaw is 59% and 58%, respectively. The error rate increment is very large compared to the increment of the mouse from mode 2 to 3; that is only 11%. The huge increment of error rate also occurs from mode 3 to 4 for Pitch-Roll and Pitch-Yaw, which is 58% and 55%, respectively. 10 4.3 Qualitative Results 15 We conducted the assessment of comfort and fatigue using a seven -question (? = 0.79) and a five-question questionnaire (? = 0.85), respectively. Each question in comfort and fatigue assessment was a 7-point Likert scale from "very low" to "very high" levels of comfort; however, in the fatigue test, the scale is from "very high" to "very low" levels of fatigue; therefore

option 7 is the best impression. Figure 7 shows the results of the comfort questionnaire 1

(items 1 to 7) and fatigue questionn aire (items 8 to 12). Table IV describes the mean result of the questionnaire. By far, all subjects were most comfortable with the mouse over the Pitch -Roll and Pitch-Yaw in all items. For a representative report, we take item number 7 ("Overall operation of input device") as an indicator ($U=27.5$, $p<0.05$) for Mouse compared to Pitch-Roll and ($U=46$, $p<0.05$) for Mouse compared to Pitch-Yaw. Another significant difference is in items 10, 11, and 12 (arm, shoulder, and neck fatigue); it was reported that Pitch -Yaw was less in fatigue than Pitch-Roll gesture was ($U=89.5$, $p=0.006$; $U=107.5$, $p=0.029$; and $U=109.5$, $p=0.035$). The other assessment is RPE by using the Borg scale (0, 0.5, 1-10 scale; from "nothing at all" to "very, very strong (almost max.)") which is conducted on arm, shoulder, and neck effort assessment. Table V describes th e details of RPE assessment result. The Spearman's rank-order correlation revealed that the shoulder's effort of Pitch-Roll and Pitch-Yaw relationship had a strong and positive correlation, which was statistically significant ($rs=0.77$, $p<0.05$). We found that the assesment of effort on arm is superior in all devices, it needs more effort to move the cursor to the targets . 5 Discussion The result of performance assessment as in Table II that was indicated by throughput revealed that the TP of the mouse is 4.73 bps. This is in line with prior studies that have noted the

range of the mouse' s TP is 3.7-4.9 bps (Soukoreff and MacKenzie, 2004) and also 1 in

(MacKenzie and Jusoh, 2001) where the range is 3.0-5.0 bps. The result of the experiment ensures that the 30 methodology, experimental apparatus, data collection, etc. is apparently suitable with other researchers' technique. The results of TP of two gestures,Pitch-Roll and Pitch-Yaw, are not statistically different although the TP of Pitch-Yaw is larger than the TP of Pitch-Roll. Similarly, on the comfort rating scale, the subjects have a betterimpression of Pitch-Yaw than Pitch-Roll, indicated by the Likert score of Pitch-Yaw exceeding that of Pitch-Roll. The TP of Pitch-Yaw and Pitch-Roll is not statistically different. To understand which part of the index of difficulty causes the significant difference, we conducted a paired samples test, as shown in Table III. The results of this study indicate that a comparison of mode 3 and mode 4 is statistically different in TP as well as in tm, which is t(2)=30.96,p=0.001 for Pitch-Roll and t(2)=19,89,p=0.003 for Pitch-Yaw, respectively. Similarly, we found that comparisons of TP in modes 2 and 3 are statistically different (t(2)= -25.06, p=0.002). Based on Table II, we suspect that the level of difficulty in modes 3 and 4, for both the Pitch-Roll and Pitch-Yaw, is not a suitable taskfor the sensor. 10 Based on this,we hope this analysis gives the suggestion forapplication development using the orientation sensoras a point ing device. The error rate increment for Pitch-Roll, as shown in Table II and Fig. 6, is 59% and 58% for mode 3 to mode 4 and mode 2 to mode 3, respectively. While in Pitch-Yaw, we found the increment error rate is 58% and 55% for mode 3 to mode 4 and mode 2 to mode 3, respectively. This result strengthens oursuspicion that the difficulty level such as in mode 3 and mode 4 is 15 not in accordance with the taskof orientation sensoras a pointing device. As shown in Fig. 6, the other finding is the erro r rate of Pitch-Yaw being higher than the Pitch-Roll's in all modes. This finding is contrary to the result of the comfortness score of Pitch-Yaw over Pitch-Roll in the qualitative results. The qualitative result was concluded in Table IV and Fig. 6; we found that Cronbach's alpha is 0.79 and 0.85 for comfort items and fatigue assessment items, respectively. This indicates that all items have a satisfactory level of reliability as t his research is in the early stage as stated in (Nunnally, J.C.; Bernstein, 1994). The subjects' opinion yields that Pitch-Yaw has lower fatigueness in arm, shoulder, and neck than Pitch-Roll has (U=89.5, p=0.006; U=107.5, p=0.029; and U=109.5, p=0.035). Through the RPE using the Borg scale, the other finding revealed that Pitch-Roll and Pitch-Yaw gestures have a strong and positive correlation to the shoulder's effort. These gestures have the same effect of fatigueness on the shoulderdue to the position of the forearm during experiments, i.e., the forearm rests on the chair armrest. 6 Conclusion The aim of the present research was to examine the hand orientation to substitute the computer mouse movement; it was evaluated based on ISO/TS 9241 part 411:Ergonomics ofthe human-systeminteraction standard.Two pairs of hand orientation candidates were evaluated in terms of Pitch-Roll and Pitch-Yaw, by substituting up-down and left-right mouse cursor movements. 30 Although almost all the scores of Pitch-Yaw overpass the scores of Pitch-Roll, surprisingly, no statistically significant differences were found in throughput and movement time. Perhaps the most important finding was that the significant difference among the index of difficulty is fullfilled. Therefore, the statisticalanalysis revealed that the index of difficulty (ID) of very low and low task (ID ≤ 4); in our experiment this is marked by mode 1 and mode 2; is a suitable ID when using the orientation sensor as a cursor emulation. The second major finding was that in terms of fatigueness of arm, shoulder, and neck, the Pitch-Yaw gesture has a lower significance of fatigueness than the Pitch -Roll gesture. This study provides the first comprehensive assessment of hand gestures, i.e., Pitch -Roll and Pitch-Yaw to emulate a mouse for human-computer interaction based on ISO 9241-411 evaluation procedures. The empirical findings in this study provide a new suggestion of a suitable level of difficulty when using an orientation sensor to emulate the movement of a mouse cursor.

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