I. Penjelasan bukti korespondensi, pertanyaan reviewer, dan revisi dari penulis

Judul artikel:

" A study of hand-movement gestures to substitute for mouse placement using an inertial sensor"

Link portal management system; Semua history bisa diperiksa pada link berikut:

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user ID : 473102
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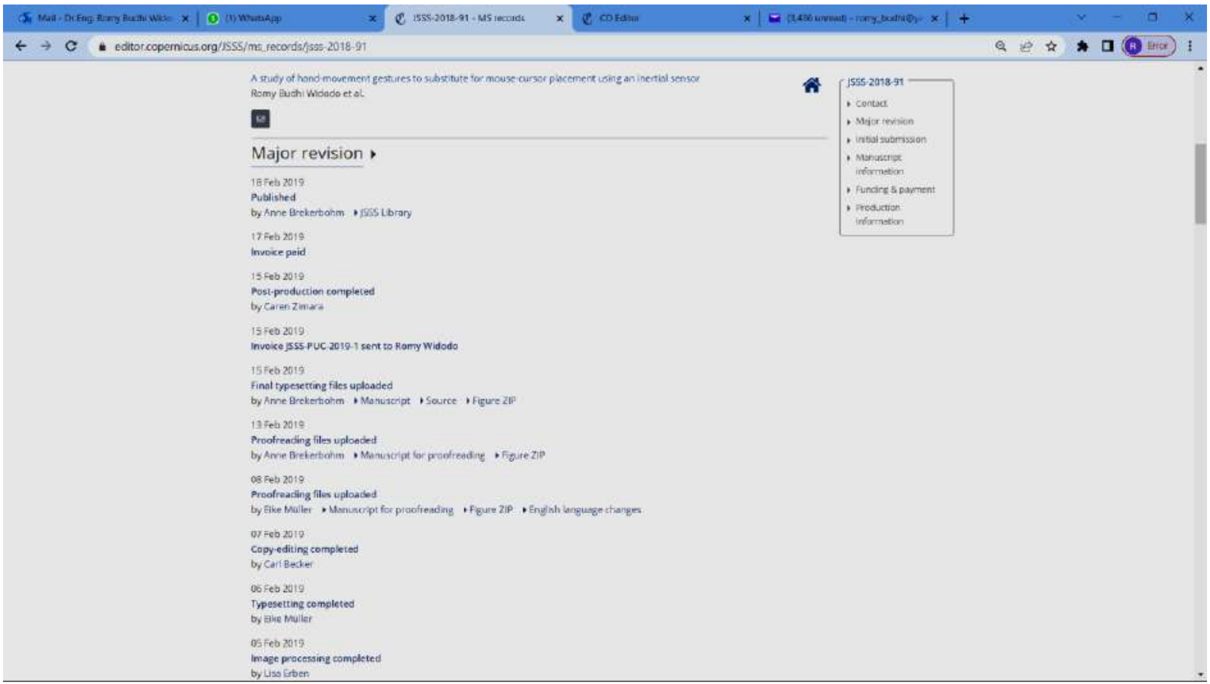

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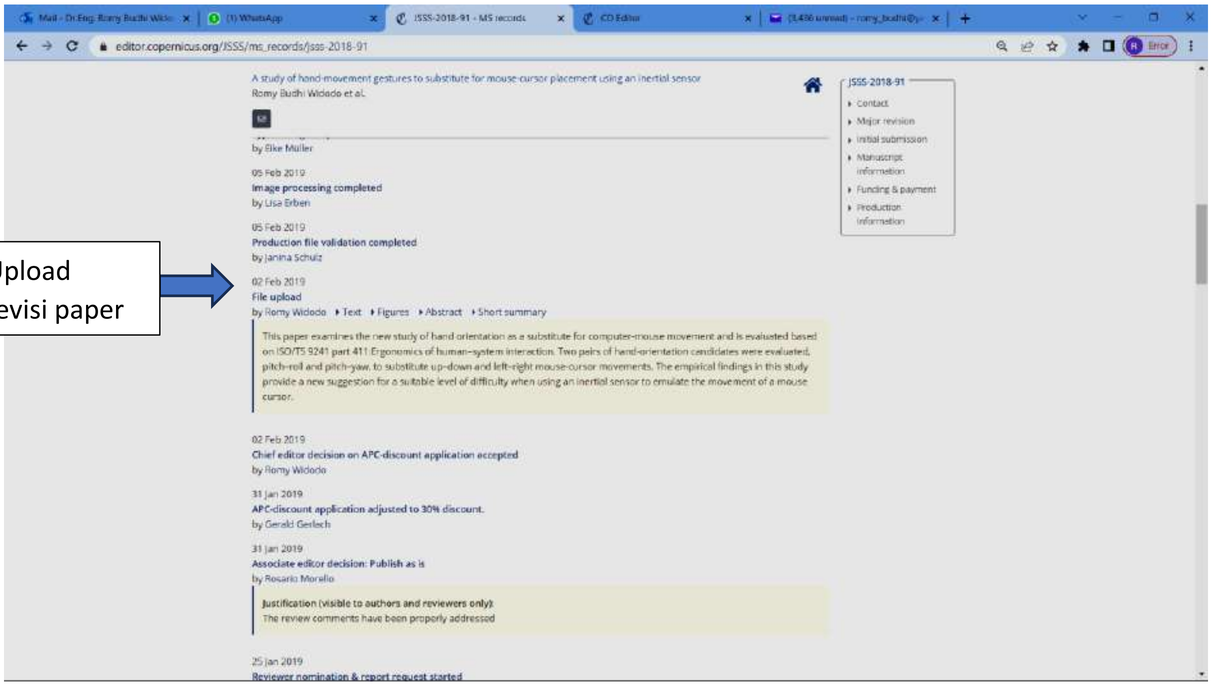
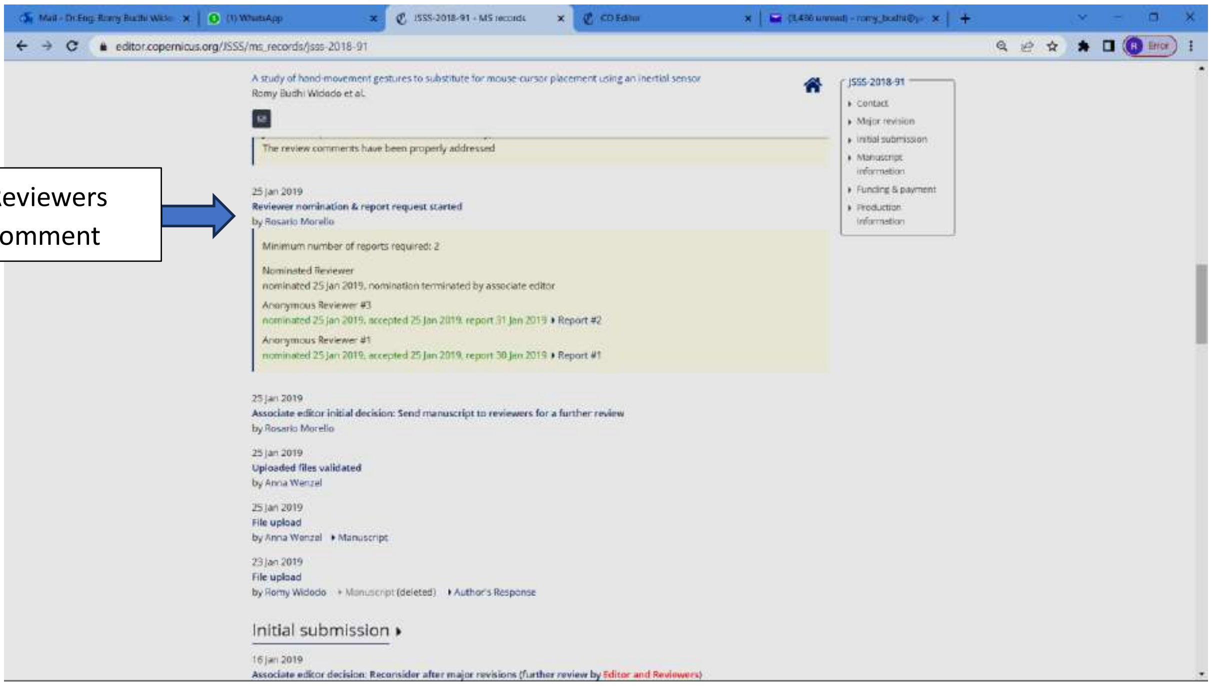
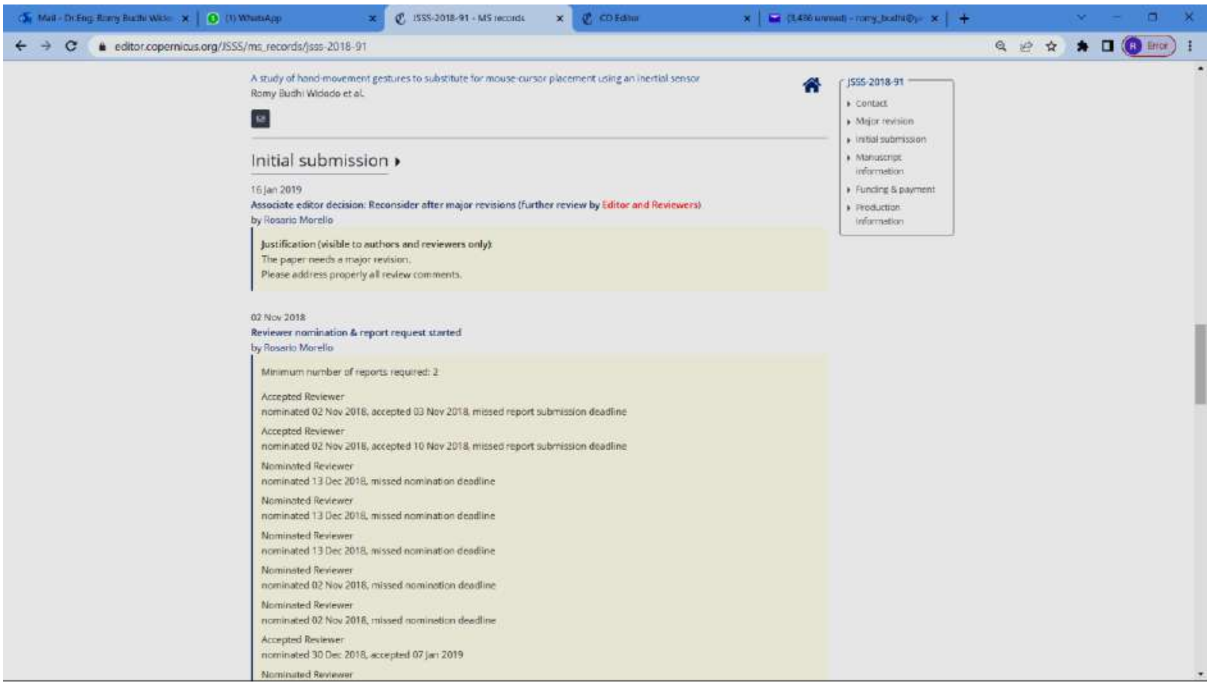


Reviewers comment





Bukti korespondensi:

Pengiriman artikel dan registrasi:

jsss-2018-91 (author) - manuscript successfully registered

From: editorial@copernicus.org

To: romy_budhi@yahoo.com

Cc: wada@brain.kyutech.ac.jp

Date: Monday, October 22, 2018 at 05:19 PM GMT+7

Dear Romy Widodo,

Thank you very much for registering a manuscript for publication in Journal of Sensors and Sensor Systems (JSSS). We hav
your registration with the following information:

Title: Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor
Author(s): Romy Widodo, Reyna Quita, Rhesdyan Setiawan, and Chikamune Wada
MS No.: jsss-2018-91
MS Type: Regular research article
Iteration: Initial Submission

Before uploading your files, you still have the opportunity to edit your manuscript data at:
https://editor.copernicus.org/JSSS/ms_records/jsss-2018-91

We kindly ask you to upload the files required for the review process using your File Manager no later than 25 Oct 2018:
https://editor.copernicus.org/JSSS/file_manager/jsss-2018-91. Please find all information on manuscript submission under
https://www.journal-of-sensors-and-sensor-systems.net/for_authors/submit_your_manuscript.html.

To log in, please use your Copernicus Office user ID 473102.

You are invited to monitor the processing of your manuscript via your MS Overview:
https://editor.copernicus.org/JSSS/my_manuscript_overview

In case any questions arise, please contact me. Thank you very much for your cooperation.

Kind regards,

Natascha Töpfer
Copernicus Publications
Editorial Support
editorial@copernicus.org

on behalf of the JSSS Editorial Board

Pengumuman major revision sebelum proses review:

jsss-2018-91 (author) - manuscript needs Major Revisions

From: editorial@copernicus.org

To: romy_budhi@yahoo.com

Cc: wada@brain.kyutech.ac.jp

Date: Wednesday, January 16, 2019 at 02:40 PM GMT+7

Dear Romy Widodo,

We are pleased to inform you that the Associate Editor report for the following manuscript is now available:

Journal: JSSS
Title: Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor
Author(s): Romy Widodo et al.
MS No.: jsss-2018-91
MS Type: Regular research article
Iteration: Major Revision

The Associate Editor has decided that Major Revisions are necessary before the review process can be continued. Please find the Associate Editor report at https://editor.copernicus.org/JSSS/ms_records/jsss-2018-91.

We kindly ask you to revise your manuscript accordingly and to upload the revised files, a point-by-point reply to the comments, and a marked-up manuscript version showing the changes made in your File Manager no later than 27 Feb 2019: https://editor.copernicus.org/JSSS/file_manager/jsss-2018-91. Please find all information on manuscript submission under https://www.journal-of-sensors-and-sensor-systems.net/for_authors/submit_your_manuscript.html.

Your revised manuscript will be reviewed again and you will be informed about the outcome by separate email.

Besides adjustments requested by the Associate Editor or Reviewers, please check your manuscript carefully for typos, missing co-authors and their affiliations, terminology, updates of data in tables, or updates of variables in equations. All these have to be clarified with the Associate Editor and therefore have to be included before you submit your revised manuscript. Should your manuscript be finally accepted it will not be possible to include such rather substantial changes anymore when your manuscript is in final production (proofreading).

To log in, please use your Copernicus Office user ID 473102.

You are invited to monitor the processing of your manuscript via your MS Overview:
https://editor.copernicus.org/JSSS/my_manuscript_overview

In case any questions arise, please contact me. Thank you very much for your cooperation.

Kind regards,

Natascha Töpfer
Copernicus Publications
Editorial Support
editorial@copernicus.org

Perbaikan references:

jsss-2018-91

From: Anna Wenzel (anna.wenzel@copernicus.org)

To: romy_budhi@yahoo.com

Date: Thursday, January 24, 2019 at 04:11 PM GMT+7

Dear Romy Widodo,

Thank you very much for your manuscript submission to JSSS.

During the file check I noticed that the reference list did not fully comply with the required format. Please supply the full author list with last name followed by initials; the year should be placed at the end. Please find an example below

Porter, J. G., De Bruyn, W., and Saltzman, E. S.: Eddy flux measurements of sulfur dioxide deposition to the sea surface, Atmos. Chem. Phys., 18, 15291-15305, https://doi.org/10.5194/acp-18-15291-2018, 2018.

More detailed information can be found at https://www.journal-of-sensors-and-sensor-systems.net/for_authors/manuscript_preparation.html -> References

Could you please update the reference list accordingly and send an updated manuscript file (PDF) by email?

Thank you and kind regards,

Anna Wenzel

****
Copernicus Publications
The Innovative Open-Access Publisher

Anna Wenzel
Editorial Support

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Bahnhofsallee 1e
37081 Göttingen
Germany

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Pengumuman bahwa artikel sudah mendapat reviewer yang lengkap:

jsss-2018-91 (author) - waiting for Reviewer reports

From: editorial@copernicus.org

To: romy_budhi@yahoo.com

Cc: wada@brain.kyutech.ac.jp

Date: Friday, January 25, 2019 at 11:42 PM GMT+7

Dear Romy Widodo,

We are pleased to inform you that a sufficient number of Reviewers has agreed to review your following manuscript:

Journal: JSSS
Title: A study of hand-movement gestures to substitute for mouse cursor placement using an inertial sensor
Author(s): Romy Widodo et al.
MS No.: jsss-2018-91
MS Type: Regular research article
Iteration: Major Revision

We are now waiting for their reports and you will be informed about the outcome by separate email.

To log in, please use your Copernicus Office user ID 473102.

You are invited to monitor the processing of the manuscript via your MS Overview:
https://editor.copernicus.org/JSSS/my_manuscript_overview

In case any questions arise, please contact me.

Kind regards,

Natascha Töpfer
Copernicus Publications
Editorial Support
editorial@copernicus.org

on behalf of the JSSS Editorial Board

Pengumuman perbaikan Tables dari file yang sudah diupload:

jsss-2018-91: your uploaded .doc-file

From: Janina Schulz (janina.schulz@copernicus.org)

To: romy_budhi@yahoo.com

Date: Monday, February 4, 2019 at 02:06 PM GMT+7

Dear Romy Widodo,

Thank you for uploading your manuscript files.

I would like to inform you that I noticed during file check that all tables are inserted as images into the .doc-file you uploaded. This means that they cannot be edited. Could you please create all tables by Microsoft table tool and then send me a new .doc-file of your complete paper via email? Thank you in advance.

Kind regards,

Janina Schulz

****
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USt-IdNr.: DE216566440
Based in Göttingen, Germany
Registered in HRB 131 298
County Court Göttingen
Managing Director Thies Martin Rasmussen
****

jsss-2018-91 (author) - proofreading

From: eike.mueller@copernicus.org
To: romy_budhi@yahoo.com
Cc: wada@brain.kyutech.ac.jp
Date: Friday, February 8, 2019 at 01:29 PM GMT+7

Dear Romy Widodo,

We are pleased to inform you that your manuscript was typeset and is now available for proofreading:

Journal: JSSS
Title: A study of hand-movement gestures to substitute for mouse-cursor placement using an inertial sensor
Author(s): Romy Widodo, Reyna Quita, Rhesdyan Setiawan, and Chikamune Wada
MS No.: jsss-2018-91
MS Type: Regular research article

You are kindly asked to proofread the article. Please use Adobe Reader to highlight corrections and insert comments in the *.pdf file. This can be done by using the "Annotations" tools located on the right-hand side of the opened file under the "Comment" tab. If you are unable to use Adobe Reader, you can prepare a list of necessary corrections mentioning page, column, and line number.

Your corrections and comments in this first proofreading file should be limited to (a) responses to the publisher remarks as given in the manuscript for proofreading, (b) raising Copernicus' awareness of oversights, and (c) expressing disagreement with Copernicus' adjustments. Please also note that a possible second proofreading and any further ones will be limited to such disagreements. New issues cannot be raised anymore. The proofreading guidelines can be found at:
http://publications.copernicus.org/for_authors/proofreading_guidelines.html

Image processing was applied to your figures. Therefore, we kindly ask you to refrain from sending new figure files (except if requested in the production remarks).

Please return your corrections as a reply to this email, if possible within a few days. If you need more time, please inform us accordingly.

Please consider each point of the following check list for corrections:

- Ensure that all author names and their corresponding affiliations are correct and that the running title is appropriate.

- Ensure that the reference list is complete and correct (see https://www.journal-of-sensors-and-sensor-systems.net/for_authors/manuscript_preparation.html).

- Please ensure that all equations are displayed correctly. We aim to maintain consistency. Therefore, please check that all vectors are denoted by bold italics, matrices by bold roman, and that all scalars (e.g. components) are denoted by italics.

- Please ensure that all tables are displayed correctly.

- Please ensure that all figures are displayed correctly.

- Please look through and respond (where applicable) to the production remarks.

Your paper has received copy-editing for English. Please download and review the "English language changes" file. This file documents all of the corrections made to your paper.

- Please note that your short summary has been modified.

Please download the *.pdf file of your typeset manuscript at https://editor.copernicus.org/JSSS/ms_records/jsss-2018-91. To log in, please use your Copernicus Office user ID 473102.

Corrections after publication of the article *.pdf file are not possible. This would result in a second version of the article, which could not utilize the former article citation. Corrections after publication can therefore only be published in a corrigendum.

Please keep in mind that all URLs and DOIs corresponding to your paper (citation header, footer, and supplement) as given inside the *.pdf file are not the final ones. They include bibliographic data that will only be determined upon publication of your paper.

In case any questions arise, please do not hesitate to contact me. Thank you very much for your cooperation. I am looking forward to your reply.

Kind regards,

Eike Müller
Copernicus Publications

Pertanyaan Reviewers:

Reviewer 1: (Bukti terdapat pada link portal management system)

https://editor.copernicus.org/JSSS/ms_records/jsss-2018-91

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Report #1

Submitted on 06 Dec 2018
Anonymous Reviewer #1

Check-List for Reviewers

General Information

Does the subject of this paper fit to "Sensors and Sensor Systems"?	**Yes** No
Does the paper contain new and substantial results which differ significantly from previous publications of the author?	**Yes** No
Is the scientific quality of the paper internationally on a sufficiently high level?	Yes **No**
Are the title and the abstract pertinent and understandable to a wide audience?	**Yes** No
Is the presentation clear and concise? (1 = strongly disagree, 5 = strongly agree)	1 2 3 **4** 5
Is the text fluent and precise? (1 = strongly disagree, 5 = strongly agree)	1 2 3 **4** 5
Please rate the overall quality of this paper (1 = very poor, 10 = outstanding):	1 **2** 3 4 5 6 7 8 9 10

Recommendation to the Editor

The manuscript is acceptable **as it is.**
The manuscript is acceptable with **technical corrections**.
The manuscript will be acceptable after **minor revisions**.
The manuscript may become acceptable after **major revisions** and must be reviewed again:
I am willing to review the revised paper.
I am not willing to review the paper again.
The manuscript is not acceptable.

Comments to the Author

A substantial and adequate discussion of the measurement results is unfortunately missing.

Reviewer Report:
jsss-2018-91-referee-report.pdf

Review Report

1. The title is appropriate

2. The abstract is appropriate

3. Some abbreviations (e.g. DOF) are not explained, the authors need to indicate the meaning at least once in the text.

4. Introduction and experimental details are well described

5. Discussion section is basically a repetition of results, the authors need to give a profound discussion on statements like ‘This result strengthens our suspicion that the difficulty level such as in mode 3 and mode 4 is not in accordance with the task of orientation sensor as a pointing device.’ and others in this section.

Reviewer 2: (Bukti terdapat pada link portal management system)

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Report #2

Submitted on 13 Dec 2018
Anonymous Reviewer #2

Check-List for Reviewers

General Information

Does the subject of this paper fit to "Sensors and Sensor Systems"?	**Yes** No
Does the paper contain new and substantial results which differ significantly from previous publications of the author?	**Yes** No
Is the scientific quality of the paper internationally on a sufficiently high level?	**Yes** No
Are the title and the abstract pertinent and understandable to a wide audience?	**Yes** No
Is the presentation clear and concise? (1 = strongly disagree, 5 = strongly agree)	1 2 **3** 4 5
Is the text fluent and precise? (1 = strongly disagree, 5 = strongly agree)	1 2 **3** 4 5
Please rate the overall quality of this paper (1 = very poor, 10 = outstanding):	1 2 3 4 5 6 **7** 8 9 10

Recommendation to the Editor

The manuscript is acceptable as it is.
The manuscript is acceptable with **technical corrections**.
The manuscript will be acceptable after **minor revisions**.
The manuscript may become acceptable after **major revisions** and must be reviewed again:
  I am willing to review the revised paper.
  I am not willing to review the paper again.
The manuscript is **not acceptable**.

Comments to the Author

Introduction and Experiment design can be written better way .

Reviewer 3: (Bukti terdapat pada link portal management system)
https://editor.copernicus.org/JSSS/ms_records/jsss-2018-91

[Editor Portal] [My Manuscript Overview] [My Manuscript Archives]

Editor
Copernicus Office

Report #3

Submitted on 09 Jan 2019
Anonymous Reviewer #3

Check-List for Reviewers

General Information

Does the subject of this paper fit to "Sensors and Sensor Systems"?	**Yes** No
Does the paper contain new and substantial results which differ significantly from previous publications of the author?	**Yes** No
Is the scientific quality of the paper internationally on a sufficiently high level?	**Yes** No
Are the title and the abstract pertinent and understandable to a wide audience?	Yes **No**
Is the presentation clear and concise? (1 = strongly disagree, 5 = strongly agree)	1 2 **3** 4 5
Is the text fluent and precise? (1 = strongly disagree, 5 = strongly agree)	1 2 3 **4** 5
Please rate the overall quality of this paper (1 = very poor, 10 = outstanding):	1 2 3 4 5 6 **7** 8 9 10

Recommendation to the Editor

The manuscript is acceptable **as it is**.
The manuscript is acceptable with **technical corrections**.
The manuscript will be acceptable after minor revisions.
The manuscript may become acceptable after **major revisions** and must be reviewed again:
I am willing to review the revised paper.
I am not willing to review the paper again.
The manuscript is **not acceptable**.

Comments to the Author

This manuscript describes a qualitative study on throughput and movement time for hand orientations (e.g. pitch-roll and pitch-yaw) using Ergonomics of human-system interaction standard. This study utilised different levels of difficulty including high, medium, low, and very low to assess the comfort movement with comfort-rating scales. Overall, the experimental design is appropriate and the results are mildly considerable for publication. The error rate is quite high, especially at high levels of difficulties hence the authors should intensively discuss how to improve the reliability and accuracy of the speed/direction of hand. The quality of presentation is relatively low and the quality of Figures should be improved. Writing should be more concise, pertinent and more readable to a wide audience, especially the abstract. Discussion on the lower fatigueness of Pitch-Yaw compared to Pitch-Roll should be given.

Reviewer #3

This manuscript describes a qualitative study on throughput and movement time for hand orientations (e.g. pitch-roll and pitch-yaw) using Ergonomics of human-system interaction standard. This study utilised different levels of difficulty including high, medium, low, and very low to assess the comfort movement with comfort-rating scales. Overall, the experimental design is appropriate and the results are mildly considerable for publication.

1. The error rate is quite high, especially at high levels of difficulties hence the authors should intensively discuss how to improve the reliability and accuracy of the speed/direction of hand.

2. The quality of presentation is relatively low and the quality of Figures should be improved.

3. Writing should be more concise, pertinent and more readable to a wide audience, especially the abstract.

4. Discussion on the lower fatigueness of Pitch-Yaw compared to Pitch-Roll should be given.

Surat kepada Editor dari Penulis dan Hasil Revisi dengan Tanda Warna

January 23, 2019

Dear Dr. Rosario Morello
(Associate Editor of Journal of Sensors and Sensor Systems)

Please find the enclosed document containing our responses to the reviewers and a marked-up in green color of the manuscript version of jsss-2018-91: "Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor," Romy Widodo et al.

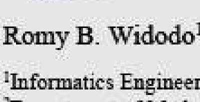
We have modified the manuscript to address all of the comments of the reviewer. The modifications are made in detail as in the individual letter to the Reviewer #1, Reviewer #2, and Reviewer #3. On the File Manager management system in JSSS website, we have succeeded upload the revised paper. If permitted, we would like to change the title for English usage, the editing does not affect meaning. The new title is "A study of hand-movement gestures to substitute for mouse cursor placement using an inertial sensor."

The made changes as follows:

- The major revision is in discussion part. We have added an adequate discussion about measurement result and added Table II, as suggested by Reviewer #1. And also adding some references to support some statements as a profound discussion suggested by Reviewer #1.
- We have added a paragraph in experiment design section to address the Reviewer #2's suggestion.
- We have added a paragraph to discuss how to improve the reliability and accuracy of the speed/direction of hand;and also we have revised the abstract to be more readable to a wide audience, as suggested by Reviewer #3.
- The explanation about how the fatigueness of Pitch-Yaw is lower than Pitch-Roll gesture is added to address Reviewer #3's suggestion.
- Figure 2 and Fig.3 have been modified to enhanced its quality to address the comment of Reviewer #3.

We sincerely appreciate the helpful comments and suggestions.
Thank you very much for facilitating this submission.

Sincerely,



Romy B. Widodo[1], Reyna M. Quita[2], Rhesdyan W. Setiawan[1], and Chikamune Wada[3]

[1]Informatics Engineering Study Program, Ma Chung University, Malang, 65151, Indonesia
[2]Department of Mathematics, Faculty of Science, National Central University, Taoyuan City, 32001, Taiwan
[3]Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Wakamatsu, Fukuoka, 808-0196, Japan

January 23, 2019

Responses to **Reviewer #1** of jsss-2018-91: "Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor," Romy Widodo et al.

Thank you very much for taking time to review our paper. We acknowledged the comments and have made some revision to address the comments, as in the reviewer and authors dialogue below.

In summary, we have added an adequate discussion about measurement result and added Table II on page 17. And also adding some references to support some statements as a profound discussion.

>Reviewer:

A substantial and adequate discussion of the measurement result is unfortunately missing.

Authors:

Thank you for your attention. In the revised version, we improved the structure and rewrote some new paragraphs in the discussion section. We have added the 3rd paragraph in discussion section on page 8: "*The error rate of the mouse* ......" The paragraph contains the explanation of the measurement result of error rate and some relevant references from the previous studies. The new discussion tried to link between the great error rate of some *modes* of experiment and the level of difficulty of the experiment.

>Reviewer:

Some abbreviations (e.g. DOF) are not explained, the authors need to indicate the meaning at least once in the text.

Authors:

We appreciate and agree with your point. After the revision process, we added new sentences to explained the degree of freedom (DOF) in the beginning of Section 3.3 **Apparatus/materials** (on page 5, line 24-26). We marked up the sentences: "*The experiment involves the measurements ......the systems's bodies.*" And also the other abbreviation is explained, "*ISO/TS (International Standards Organization/Technical Specification)*" on page 3, line 1.

>Reviewer:

Discussion section is basically a repetition of results, the authors need to give a profound discussion on statements like 'This result strengthens our suspicion that the difficulty level such as in mode 3 and mode 4 is not in accordance with the task of orientation sensor as a pointing device.' and others in this section.

Authors:

We appreciate your suggestion. The results regarding task's level of difficulty, finally strengthens our suspicion, which task's level of difficulty is in accordance with the task of orientation sensor as a pointing device. We have added the 3rd paragraph (on page 8, line 26 to end) and found that the arm jitter is one of the caused of big errors. This is also supported by some previous research as mentioned in that paragraph (on page 9, line 5). We also added how to improve the accuracy based on our supposition in the 4th paragraph (on page 9, line 12-16)
Thank you for your attention.

We sincerely appreciate your constructive comments. We believe that these have greatly strengthened the paper.

Thank you again for your insighful suggestions and for taking the time to review this paper.

Sincerely,

Romy B. Widodo[1], Reyna M. Quita[2], Rhesdyan W. Setiawan[1], and Chikamune Wada[3]

[1]Informatics Engineering Study Program, Ma Chung University, Malang, 65151, Indonesia
[2]Department of Mathematics, Faculty of Science, National Central University, Taoyuan City, 32001, Taiwan
[3]Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Wakamatsu, Fukuoka, 808-0196, Japan

January 23, 2019

Responses to **Reviewer #2** of jsss-2018-91: "Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor," Romy Widodo et al.

Thank you very much for taking time to review our paper. We have addressed your comment, as in the reviewer and author dialogue below.

>Reviewer:
Introduction and experimental design can be written better way.

Authors:
We appreciate your point. In the experimental design before, we consider that there is no explanation about the design of data analysis. We have added the design of data analysis in the Experiment Design section on page 5, line 17-22: "*The design for statistical analysis is as follows....*"

We sincerely appreciate your constructive comments. We believe that these have greatly strengthened the paper.
Thank you again for your insighful suggestions and for taking the time to review this paper.

Sincerely,

Romy B. Widodo[1], Reyna M. Quita[2], Rhesdyan W. Setiawan[1], and Chikamune Wada[3]

[1]Informatics Engineering Study Program, Ma Chung University, Malang, 65151, Indonesia
[2]Department of Mathematics, Faculty of Science, National Central University, Taoyuan City, 32001, Taiwan
[3]Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Wakamatsu, Fukuoka, 808-0196, Japan

January 23, 2019

Responses to **Reviewer #3** of jsss-2018-91: "Study of hand movement gestures to substitute the mouse cursor placement using inertial sensor," Romy Widodo et al.

Thank you very much for taking time to review our paper. We acknowledged the comments and have made some revision to address the comments, as in the reviewer and authors dialogue below.

In summary, we have added the discussion about how to improve the accuracy regarding the high error rate. And also the deep discussion about the lower fatigueness of Pitch-Yaw compared to Pitch-Roll gesture. The abstract and some figures have been modified to enhanced its quality to address the comment.

>Reviewer:

The error rate is quite high, especially at high levels of difficulties hence the authors should intensively discuss how to improve the reliability and accuracy of the speed/direction of hand.

Authors:

Thank you for your constructive question. In the discussion section, we have added the discussion about the possible cause of a large error, such as: arm jitter. The suggestion of the improvement of accuracy and reliability has been added to the discussion on page 9, line 12-16: "*In the future, a more-rigorous pointing device using inertial sensor needs......*"

>Reviewer:

The quality of presentation is relatively low and the quality of Figures should be improved.

Authors:

Thank you for your attention. To improve the quality of Figures, some figures has been modified and clarified.

-We have modified Figure 1, we added the normal angle to every movement of the wrist on page 12.

-In the Figure 2, the modification such as adding the enlargement line have clearly made the figure more understandable (on page 13).

-The other modification is in the Figure 3, the figure used a real picture of Subject during experiment activities (on page 13).

-The modification of Figure 7 on page 16 lies on the addition of axis title.

>Reviewer:

Writing should be more concise, pertinent and more readable to a wide audience, especially the abstract.

Authors:

Thank you for pointing this out. We have modified the abstract, we tried to rephrase sentences in Abstract section as on page 1.

>Reviewer:

Discussion on the lower fatigue of Pitch-Yaw compared to Pitch-Roll should be given.

Authors:

Thank you for your valuable suggestion. We have modified the discussion section. We explored the discussion about lower fatigue of Pitch-Yaw gesture. The qualitative results was discussed in the 5th paragraph on page 9, line 21-31: "*Overall Pitch-Yaw results in less fatigue compared to Pitch-Roll, and this .....* "

We sincerely appreciate your constructive comments. We believe that these have greatly strengthened the paper.

Thank you again for your insighful suggestions and for taking the time to review this paper.

Sincerely,

Romy B. Widodo[1], Reyna M. Quita[2], Rhesdyan W. Setiawan[1], and Chikamune Wada[3]

[1]Informatics Engineering Study Program, Ma Chung University, Malang, 65151, Indonesia
[2]Department of Mathematics, Faculty of Science, National Central University, Taoyuan City, 32001, Taiwan
[3]Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Wakamatsu, Fukuoka, 808-0196, Japan

Hasil Revisi dengan Tanda Warna

A study of hand-movement gestures to substitute for mouse cursor placement using an inertial sensor

Romy Budhi Widodo[1], Reyna Marsya Quita[2], Rhesdyan Wicaksono Setiawan[1], Chikamune Wada[3]

[1]Informatics Engineering Study Program, Ma Chung University, Malang, 65151, Indonesia
[2]Department of Mathematics, Faculty of Science, National Central University, Taoyuan City, 32001, Taiwan
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Abstract. This paper examines the new study of hand orientation as a substitute for computer-mouse movement and is evaluated based on ISO/TS 9241 part 411: Ergonomics of human–system interaction-Evaluation methods for the design of physical input devices. Two pairs of hand-orientation candidates were evaluated, using, for example, Pitch–Roll and Pitch–Yaw to substitute for up–down and left–right mouse-cursor movements. The up–down cursor movement was generated from the Pitch orientation, while the left–right cursor movement was generated from the Roll or Yaw orientation, depending on the evaluation of the proposed gesture. The research employed a standard computer mouse as a baseline comparison for the study. The empirical study was conducted to evaluate quantitative performance such as throughput and movement time. The best impression resulted when the throughput had the greatest value as well as the shortest movement time. The performance test was based on Fitts's law using a multi-directional tapping test as suggested by ISO/TS 9241-411. The test was divided into several levels of difficulty including high, medium, low, and very low. The other assessment is qualitative and was performed using the comfort-rating scale questionnaire and rating of perceived exertion of comfortability and fatigue. The quantitative results show that Pitch–Yaw throughput is slightly higher than for the Pitch–Roll gesture, and that the movement time in Pitch–Yaw is slightly less than in Pitch–Roll, although there is not a statistically significant difference between the two. We also found that Pitch–Yaw movements have a higher level of comfort based on the comfort-rating scale test. Since the test was divided into levels of difficulty, we identified those gestures suitable for the task with a low and very low level of difficulty based on throughput, movement time, and error-rate results. Finally, this study suggests that Pitch–Roll and Pitch–Yaw movements of the hand can be used as substitutes for the mouse, and that Pitch–Yaw movements are superior in regard to causing less fatigue than Pitch–Roll movements. Furthermore, this study provides a new suggestion for 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

1 Introduction

A computer mouse's main function is as a pointing device for the user to navigate, target, and command execution through mouse movement and button-clicked action (Lazar, Jonathan; Feng, Jinjuan Heidi; Hochheiser, 2017) and (Natapov, Castellucci, & MacKenzie, 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 sensor was also used in edutainment as a control (Kranz, Holleis, & Schmidt, 2010); fiberoptic in (Zimmerman, Lanier, Blanchard, Bryson, & Harvill, 1986); flexible plastic resistive ink sensor as 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), (I. S MacKenzie & Jusoh, 2001), and (Norman & Norman, 2010). The use of optic type such as a laser pointer as a pointing device have been discussed in (Myers et al., 2002) and (Oh & Stuerzlinger, 2002). Much of the current literature on pointing devices pays particular attention to others evaluating and comparing pointing devices; 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 of flexion-extension and radial-ulnar deviation; the forearm movement consist of forearm pronation and forearm supination as in (Gates, Walters, Cowley, Wilken, & Resnik, 2016) and (Nelson D.L.; Mitchell M.A.; Groszewski P.G.; Pennick S.L.; Manske P.R., 1994). In this paper we 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: 38° and 40°; wrist radial and ulnar deviation: 28° and 38°; and forearm pronation and supination: 13° and 53°.

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), (I. S MacKenzie & Jusoh, 2001), (Norman & Norman, 2010), (I. Scott MacKenzie, Kauppinen, & Silfverberg, 2001), and (Widodo & 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/TS (International Standards Organization/Technical Specification) 9241 part 411: evaluation methods for the design of physical input devices.

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

ISO 9241 is a standard used for human-system interaction (International Organization for Standardization, 2012). ISO 9241 part 411 (ISO/TS 9241-411) discusses the evaluation methods for the design of physical input devices. The quantitative assessment of performance was measured by throughput and movement time, as well as using a comfort-rating scale to assess comfort 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 (I_D) divided by movement time (t_m) (Fitts, 1954) and (Mackenzie, 2018). Based on the Shannon-Hartley theorem, the formulation of the I_D is in (1):

$$ID = \log_2 \frac{d+w}{w} \text{ (bit)} , \qquad (1)$$

where d is the distance of movement, and w is the target width. The ISO procedure includes the four levels of difficulty (I_D), such as high ($I_D > 6$); medium ($4 < I_D \leq 6$); low ($3 < I_D \leq 4$); and very low ($I_D \leq 3$).

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 calculated using this adjustment for accuracy. The equation (1) was modified to be in (2):

$$ID_e = \log_2 \frac{d+w_e}{w_e};\ w_e = 4133.s_x \qquad (2)$$

$$TP = \frac{ID_e}{t_m} \qquad (3)$$

where w_e is the effective target width and s_x is the standard deviation of the clicked target's coordinate. The movement time (t_m) was calculated from one target to the other target in *seconds*. Finally, the *TP* is the *effective index of difficulty* (ID_e) divided by t_m 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-directional tapping task. The evaluation using the multi-directional tapping task was used in (Norman & Norman, 2010), (I. Scott MacKenzie et al., 2001), and (Douglas, Kirkpatrick, & MacKenzie, 1999). The pattern of multi-directional 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 (s_x). Figure 2(b) illustrates a spreading tapping coordinates by each subject, symbolized by x, spread around the centre of circle (x_c,y_c). Every clicked coordinate out of the circle will be recognized as an error.

In the beginning, the ID_e in equation (2) reserved for one-direction tapping task; the ID_e for multi-directional tapping task was calculated based on the extended of equation (2) as in (Norman & Norman, 2010) and (International Organization for Standardization, 2012). For the calculation conducted in each small circle, all clicked coordinates are analysed relative to (x_c, y_c) and finally will be averaged. Hereafter, all equations are for the multi-directional tapping task. Equation (4) calculates the mean of the clicked coordinates and, then in (5), the subtraction for each x and y coordinate.

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} x_i \; ; \quad \overline{Y} = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{4}$$

$$\hat{x} = x_i - \overline{X} \; ; \quad \hat{y} = y_i - \overline{Y} \tag{5}$$

The two dimension standard deviation as in (6).

$$s_x = \sqrt{\frac{1}{N}\sum_{i=1}^{N} d_i^2} \tag{6}$$

The distance d is formulated as in (7).

$$d_i^2 = \hat{x}^2 + \hat{y}^2 \tag{7}$$

The calculation of the *effective target width* (w_e) is the same as in (2), rewritten in (8). The effective index of difficulty is written in (9).

$$w_e = 4.133 s_x \tag{8}$$

$$ID_e = \log_2\left(\frac{d}{w_e} + 1\right) \tag{9}$$

Finally, the throughput (TP) as in (3) is rewritten in (10) as the performance value of the device.

$$TP = \frac{ID_e}{t_m} \tag{10}$$

3 Research Methodology

3.1 Participants

Nineteen right-handed subjects, fifteen males and four females, who were an average of 27.1 years old, standard 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) randomizing the order of experiment based on index of difficulty level (I_D *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 I_D levels using 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 2,052.

The design for statistical analysis is as follows. First, the data for *TP* and t_m were investigated using the Shapiro–Wilk test to determine whether they represented normality data. A non-parametric test using the Kruskal–Wallis H test was employed to determine whether the data deviated significantly from a normal distribution, followed by the Mann–Whitney U post-hoc test. For normal data, the homogeneity of variance test was employed. One-way ANOVA was applied if the assumption of homogeneity of variances was fulfilled, and this was followed by a post-hoc test. If the data failed the assumption of homogeneity, we employed Welch's ANOVA instead of ANOVA.

3.3 Apparatus/materials

The experiment involves the measurements of three components of rotation as independent parameters, namely pitch, roll, and yaw. The number of independent parameters referred to as degree of freedom (DOF) defines the configuration of the analysis of the system's bodies. The experiments used 3-DOF tracking InertiaCube 4™ to record the orientation angle such as pitch, roll, and yaw. The manufacturer's accuracy specification: 1° in yaw, 0.25° in pitch and roll at 25°C. 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-directional tapping task simultaneously. Software specification was designed to fulfil the Annex B of ISO/TS 9241-411 which consists of: 1) four 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

The illustration of the system is 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 sensor was mounted on the back of the dominant hand, which is the middle part of the dorsal surface. The right and left mouse click event were the same for all levels of test. Subjects used a conventional mouse grasped with the dominant hand as the *click part* by employ the mouse left-button. The PC monitor displays the multi-directional 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; θ_y (pitch), θ_x (roll) , and θ_z (yaw) are the rotation angles about y, x, and, z-axis, respectively. Figure 4 also describes the mapping for a sensor and 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 of the devices. The multi-directional tapping is a point-and-click task, and each session consists of 25 clicked targets, which are indicated by 25 small circles (see Fig. 2a). 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 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 (t_m)

Throughput provides a measurement of speed and accuracy. Table II describes the experiment results for throughput (*TP*) and movement time (t_m) in detail. The summary of the results include the error rate in Table III presented in "mean (standard deviation)" and will be used for further discussion. 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 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 significance 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 hypothesis: all *TP* value means are equal (i.e., $\mu_{TP\ mouse} = \mu_{TP\ Pitch\text{-}Roll} = \mu_{TP\ Pitch\text{-}Yaw}$). The alternative hypothesis (H_A) 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 Pitch–Roll and Pitch–Yaw.

The test for t_m indicates that Pitch–Yaw is $p=0.046$, suggesting evidence of non-normality. The independent Kruskal-Wallis test is summarized as follows: the mean ranks of t_m 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 t_m in Pitch–Roll category was not statistically higher than in the Pitch–Yaw ($U = 63$, $p = 0.603$). However, the t_m in Pitch–Roll category is significantly higher than in Mouse ($U = 0.0005$, $p = 0.0005$) and the t_m in Pitch–Yaw category is also significantly higher than in Mouse ($U = 0.0005$, $p = 0.0005$).

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 t_m. The dependent variable is the value of *TP* and t_m, while the independent variable is the same subject present on two occasions on the same dependent variable. Table IV 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 most 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 III. 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 rate 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.

4.3 Qualitative Results

We conducted the assessment of comfort and fatigue using a seven-question ($\alpha = 0.79$) and a five-question questionnaire ($\alpha = 0.85$), 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 (items 1 to 7) and fatigue questionnaire (items 8 to 12). Table V 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 VI describes the 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 ($r_s=0.77, p<0.05$). 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 results of a performance assessment, shown in Table III as indicated by throughput, revealed that the *TP* of the mouse is 4.73 bps. This is in line with prior studies, which have noted the range of the mouse's *TP* as 3.7–4.9 bps (Soukoreff & MacKenzie, 2004) and in (MacKenzie & Jusoh, 2001) where the range is 3.0–5.0 bps. The results of the experiment ensure that the methodology, experimental apparatus, data collection, etc. are apparently in alignment with other researchers' techniques.

The results of the *TP* of two gestures, Pitch–Roll and Pitch–Yaw, are different with the *TP* of the mouse. Since the *TP* is related to precision and movement time, we found that the error rate between the mouse and the two gestures is also statistically different. However, in the case of *TP* and movement time between the two gestures, it is not statistically different, although the *TP* of Pitch–Yaw is larger than the *TP* of Pitch–Roll. To understand which part of the index of difficulty causes the significant difference, we conducted a paired samples test, as shown in Table IV. The results of this study indicate that a comparison of *mode 3* and *mode 4* is statistically different in *TP* as well as in t_m. Similarly, we found that comparisons of *TP* in *modes 2* and *3* are statistically different. Based on Table IV, we suspect that the level of difficulty in *modes 3* and *4*, for both the Pitch–Roll and Pitch–Yaw, does not represent a suitable task for the sensor. The discussion below includes the error rate and will complete the discussion of the effect of the difficulty level of the task.

The error rate of the mouse is 2.81%; Pitch–Roll is 28.19% and Pitch–Yaw is 34.76% (see Table III). We believe that the large error rates in those gestures are due to the level-of-difficulty factor. Next, we omit the highest level of difficulty (*mode 4*) and recalculate the average error rate. The average error rate after omitting *mode 4* is 1.95%, 16.06%, and 20.90% for Mouse, Pitch–Roll, and Pitch–Yaw, respectively. This means there is a decrease in the error rate of 31%, 43%, and 40% for Mouse, Pitch–Roll, and Pitch–Yaw, respectively, after omitting *mode 4*. At the same time, the influence of *mode 3* and *mode 4* was investigated by omitting both of them in the analysis. We found that the error rate would be reduced to 33%, 63%, and 59% for Mouse, Pitch–Roll, and Pitch–Yaw, respectively. The research regarding arm jitter using inertial sensor measurement

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in (Noy, Alon, & Friedman, 2015)) demonstrates that arm jitter ranges from 0.7 to 1.15 Hz. This means that, to reach the 2% error rate of an underdamped response, a person needs around 0.87 to 1.43 *seconds*; relatively speaking, the time to reach the clicked target would be increased due to the number of pixels in the smaller target'. The tasks with medium and high levels of difficulty have only 20 and 12 pixels of target width, respectively (see Table I); the target's width is too small and almost the same as the target width in the studies by (Widodo & Matsumaru, 2013) and by (Myers et al., 2002). The previous studies used a laser-pointer spot interface to emulate the mouse's cursor, which is also prone to arm jitter, as in our study; in those studies, the subject experienced difficulty tapping the target. This result strengthens our suspicion that the difficulty level, such as in *mode 3* and *mode 4*, is not in accordance with the task of the orientation sensor as a pointing device.

The results of two gestures succeeded as substitute for the movement of a computer mouse. Despite this improvement, there was a significantly high error rate, especially for the medium- and high-level tasks (*mode 3* and *mode 4*). The natural jitter of the arm, as mentioned in (Noy et al., 2015), indicates that people need more time to tap the actual clicked target, such as point (x_c, y_c) in Fig. 3b. It is difficult if the diameter of the target is small, as in *mode 3* and *mode 4* tasks. In the future, a more-rigorous pointing device using inertial sensor needs to be combined with a special filter to dampen the jitter. Filtering methods such as a complementary filter and Kalman filter are important to consider in order to improve accuracy and measurement reliability. Other potential improvements for accuracy may be made by taking a mechanical approach and using, for example, an elbow band, shoulder support, and/or wrist support to dampen arm jitter.

The qualitative results were concluded in Table V and Figure 7; 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 this research is in the early stage, as stated in (Nunnally, J.C.; Bernstein, 1994). The subjects' opinions show that Pitch–Yaw results in less fatigue in the arm, shoulder, and neck than Pitch–Roll does ($U=89.5$, $p=0.006$; $U=107.5$, $p=0.029$; and $U=109.5$, $p=0.035$). Overall, Pitch–Yaw results in less fatigue compared to Pitch–Roll, and this might be caused by the muscles involved. The pitch and yaw represent the wrist movement that results from flexion–extension and radial-ulnar deviation of the wrist, respectively. However, the roll movement results from forearm movement, called pronation–supination of the forearm. Now, we would like to compare only "roll" and "yaw," since both of them use different gestures in our study. The "roll" range of motion is only 13° to the left (pronation) but 53° to the right (supination), as stated in (Gates, Walters, Cowley, Wilken, & Resnik, 2016). However, we observed that the range of motion of "yaw" is 28° to the left (radial deviation) and 38° (ulnar deviation) to the right. The pronation and radial deviation results in the cursor moving to the left of the monitor display and in the opposite direction for supination and ulnar deviation. The subject experiences greater exertion caused by the limitation of the left "roll" range of motion, which is only 13°; the subject might use effort to move above the normal limit of his/her range of motion to attempt to move the cursor to the far left of the monitor display. However, for "yaw," the range of motion is greater and reaches 28°. Thus, the Pitch–Yaw results in less fatigue than the Pitch–Roll does.

Through the rating of perceived exertion using the Borg Scale of Perceived Exertion, another finding revealed that Pitch–Roll and Pitch–Yaw gestures have a strong and positive correlation to shoulder effort. These gestures have the same effect of fatigue on the shoulder due to the position of the forearm during experiments, i.e., the forearm rests on the chair's 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 of the human-system interaction 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.

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 fulfilled. Therefore, the statistical analysis revealed that the index of difficulty (*ID*) of very low and low task ($ID \leq 4$); 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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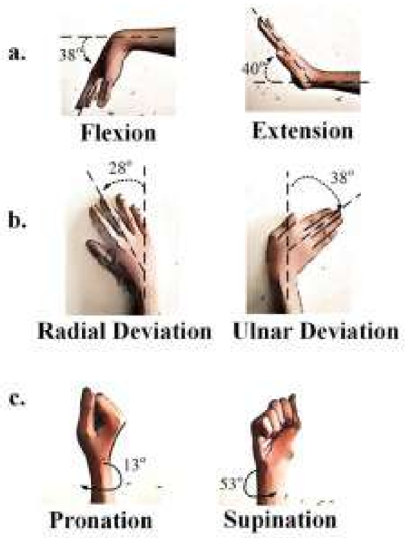


Figure 1: Wrist and forearm movement: a) flexion-extension represents pitch; b) radial-ulnar deviation represents yaw, and c) pronation-supination represents roll. The angle value is the normal value based on the previous study.

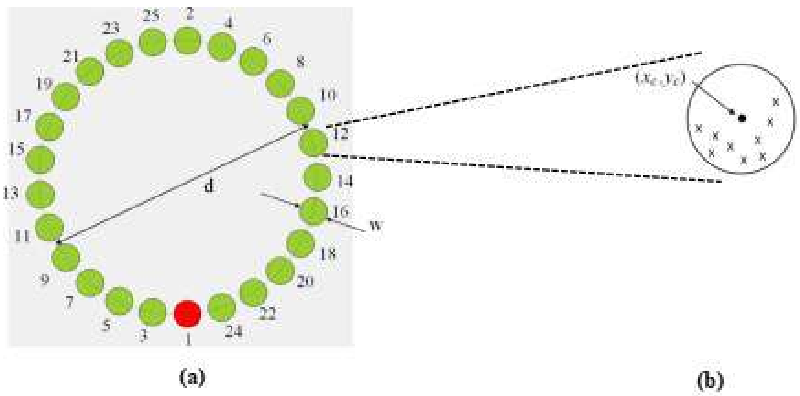
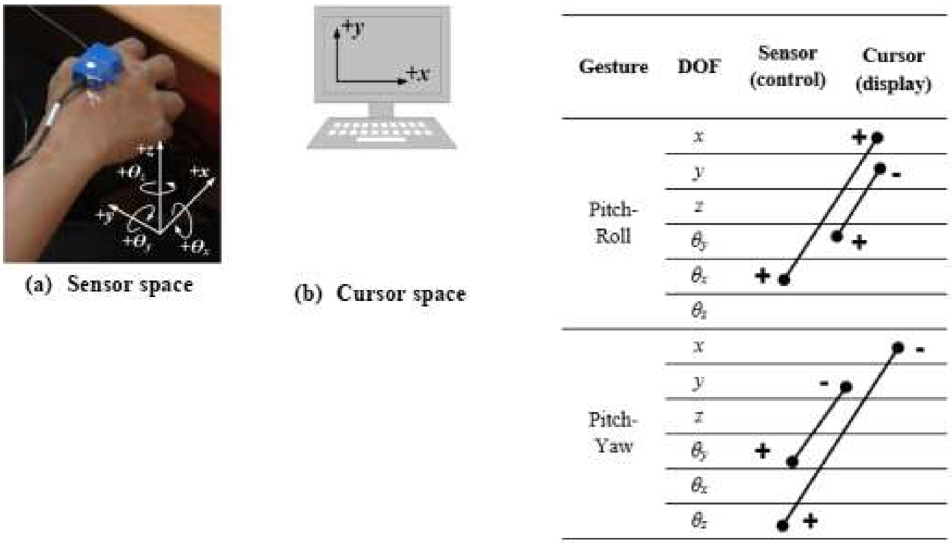


Figure 2: a) Pattern of the multi-directional tapping task: *d* = distance of movement; *w* = target width; b) Enlargement of one target circle; (x_c,y_c) is the actual clicked target; "x" indicates the clicked-coordinate spreading of each target circle.

Figure 3: Illustration of experimental conditions: 1) Subject (0.9 m from display); 2) Inertial sensor (mounted on the back of the dominant hand); 3) Click part (grasped with the dominant hand); 4) Display (computer monitor)



(a) Sensor space

(b) Cursor space

(c) Sensor-Cursor Mapping

Figure 4: (a) Orientation of sensor; (b) cursor space axes; (c) The sensor-cursor mapping, "+" and "-" sign correspondence with the direction in (a) and (b).

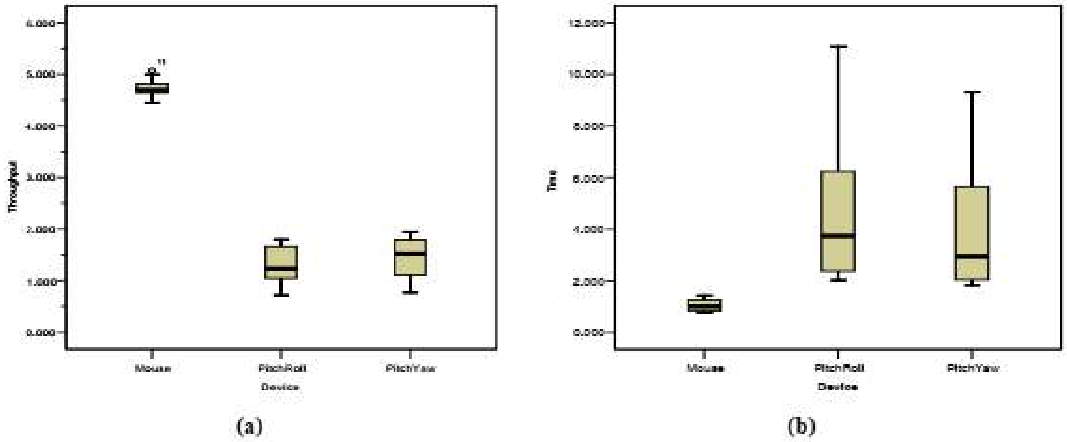


Figure 5: The boxplot of all data distribution related to a) Throughput (in *bps*) and b) Movement time (in *seconds*).

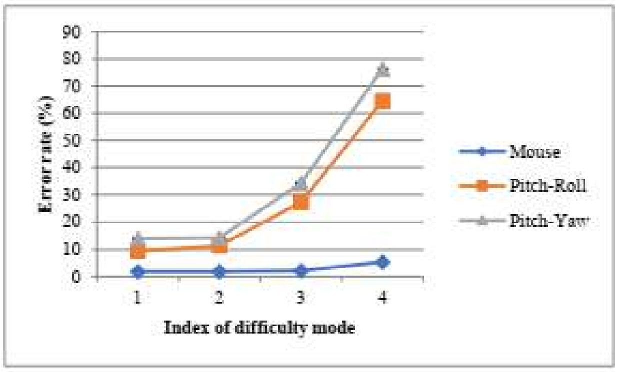


Figure 6: Error rate as a function of index of difficulty modes.

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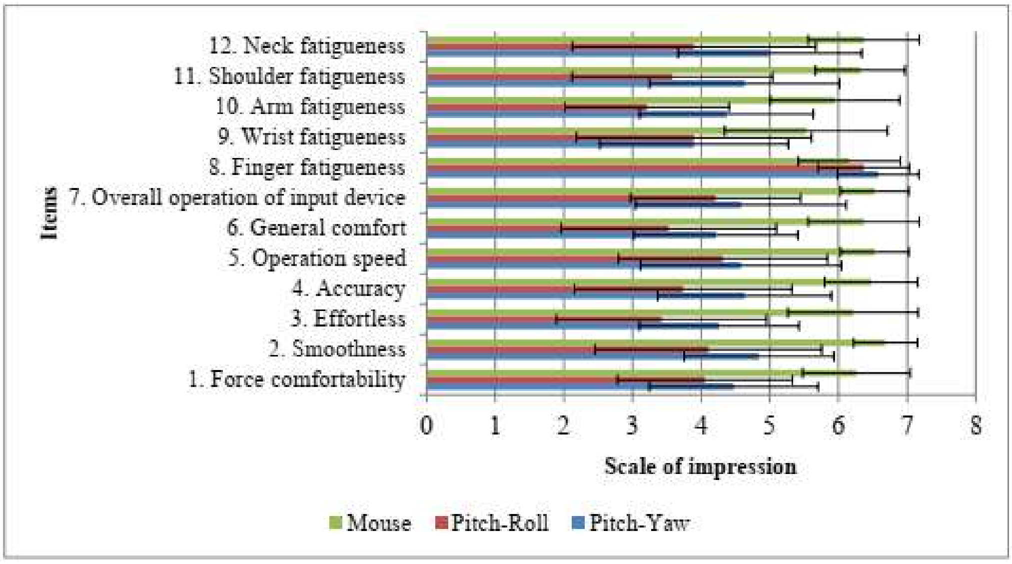

Figure 7: Results of the pointing questionnaire, where option 7 on the Likert scale is the best impression.

TABLE I

INDEX OF DIFFICULTY DESIGN (THE RANGE OF I_D IS RECOMMENDED BY ISO)

d (pixels)	**w** (pixels)	I_D (bits)	I_D **level**
350	50	3	Very low (mode 1)
600	60	3.459	Low (mode 2)
600	20	4.954	Medium (mode 3)
800	12	6.066	High (mode 4)

TABLE II
EXPERIMENT RESULTS (IN DETAILS)

B[1)]	M[2)]	ID (bits)	Mouse				Pitch-Roll				Pitch-Yaw			
			w_e (pixel)	ID_e (bits)	t_m (s)	TP (bits/s)	w_e (pixel)	ID_e (bits)	t_m (ms)	TP (bits/s)	w_e (pixel)	ID_e (bits)	t_m (ms)	TP (bits/s)
1	1	3.00	43.13	3.19	0.72	4.45	52.34	2.95	2.36	1.25	53.01	2.93	1.82	1.61
	2	3.46	53.63	3.61	0.78	4.65	63.43	3.39	2.84	1.19	65.35	3.35	2.18	1.54
	3	4.95	19.14	5.02	1.08	4.64	24.46	4.68	4.50	1.04	24.06	4.70	4.21	1.12
	4	6.07	12.24	6.06	1.35	4.47	15.76	5.70	7.93	0.72	16.18	5.66	7.41	0.76
2	1	3.00	45.32	3.13	0.66	4.71	54.92	2.88	1.73	1.67	51.47	2.97	1.64	1.81
	2	3.46	66.65	3.48	0.73	4.77	63.88	3.38	2.06	1.64	64.33	3.37	1.90	1.78
	3	4.95	19.56	4.99	1.00	5.00	23.97	4.70	3.82	1.23	24.27	4.69	3.35	1.40
	4	6.07	12.71	6.00	1.29	4.66	15.67	5.70	6.47	0.88	16.00	5.67	5.63	1.01
3	1	3.00	46.25	3.10	0.66	4.68	53.21	2.92	1.62	1.80	53.32	2.92	1.54	1.90
	2	3.46	57.10	3.53	0.73	4.85	64.75	3.36	1.89	1.78	63.68	3.38	1.74	1.94
	3	4.95	19.75	4.97	0.98	5.07	24.19	4.69	3.34	1.40	24.68	4.66	3.08	1.51
	4	6.07	12.62	6.01	1.26	4.76	15.75	5.70	5.43	1.05	16.09	5.67	5.18	1.09
	Mean				0.94	4.73			3.67	1.30			3.31	1.46

[1)]B stands for block
[2)]M stands for mode

TABLE III
EXPERIMENT RESULTS

Measurement	Device[a)]		
	Mouse	Pitch-Roll	Pitch-Yaw
TP (bps)	4.73(0.18)	1.30(0.34)	1.46(0.37)
t_m (s)	0.94(0.25)	3.67(1.96)	3.31(1.84)
Error rate (%)	2.81(0.13)	28.19(1.85)	34.76(2.13)

[a)]Presents in mean (s.d.)

TABLE IV
THE RESULT OF COMPARISON OF MEANS (PAIRED SAMPLES TEST)

	Device	Pair	t	df	p	note
Throughput	Mouse	Mode 3 - Mode 4	5.377	2	0.033	significant
		Mode 2- Mode 3	1.912	2	0.196	-
		Mode 1 - Mode 2	3.115	2	0.089	-
	Pitch-Roll	Mode 3 - Mode 4	30.962	2	0.001	significant
		Mode 2- Mode 3	-3.968	2	0.058	-
		Mode 1 - Mode 2	-4.106	2	0.055	-
	Pitch-Yaw	Mode 3 - Mode 4	19.887	2	0.003	significant
		Mode 2- Mode 3	-25.058	2	0.002	significant
		Mode 1 - Mode 2	-.615	2	0.601	-
Movement time	Mouse	Mode 3 - Mode 4	-62.528	2	0.0005	significant
		Mode 2- Mode 3	18.257	2	0.003	significant
		Mode 1 - Mode 2	33.223	2	0.001	significant
	Pitch-Roll	Mode 3 - Mode 4	-7.028	2	0.020	significant
		Mode 2- Mode 3	17.598	2	0.003	significant
		Mode 1 - Mode 2	5.804	2	0.028	significant
	Pitch-Yaw	Mode 3 - Mode 4	-7.389	2	0.018	significant
		Mode 2- Mode 3	7.450	2	0.018	significant
		Mode 1 - Mode 2	6.070	2	0.026	significant

TABLE V
QUALITATIVE RESULT

Assessment	Device[a)]		
	Mouse	Pitch-Roll	Pitch-Yaw
Mean of Comfort	6.44	3.91	4.51
Mean of Fatigue	6.06	4.19	4.89

[a)]in average using 7-point Likert scale; 7 is the best impression.

TABLE VI

THE RESULT OF RATING OF PERCEIVED EXERTION (RPE) ASSESSMENT USING BORG SCALE

Device*)	RPE score	
Mouse	Arm	1.526
	Shoulder	1.000
	Neck	1.026
Pitch-Roll	Arm	5.053
	Shoulder	4.368
	Neck	4.316
Pitch-Yaw	Arm	3.526
	Shoulder	2.579
	Neck	2.421

*)in average using Borg scale (0, 0.5, 1-10 scale); 0 is the best impression