Testing Inertial Sensor Performance as Hands-Free Human-Computer Interface

JOSIP MUSIĆ[1], MOJMIL CECIĆ[1], MIRJANA BONKOVIĆ[1]
[1]Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
University of Split
R. Boškovića b.b.
CROATIA
jmusic@fesb.hr, mcecic@fesb.hr, mirjana@fesb.hr http://labacs.fesb.hr

Abstract: - The paper introduces hands-free human-computer interface designed around commercially available inertial sensor pack. It is primarily intended to provide computer access for people with little or no upper-limb functionality, but can be used by able bodied subject in certain application scenarios. The performance of the proposed device was evaluated on twelve healthy subjects performing multi-directional point-and-select task with throughput as the main performance parameter. The system was tested using two different pointer control schemes, as well as three selection techniques. Test subjects were given two questionnaires (one per control scheme) in order to provide comfort assessment of the device and short post-measurement interviews with test subjects provided user feedback. Obtained performance and comfort assessment results are presented and discussed.

Key-Words: - inertial sensors, head-joystick, throughput, performance evaluation, human-computer interface

1 Introduction

Personal computers are ubiquitous in everyday life, and with development and application of more and more sophisticated software and with new and innovative applications, have the ability to increase life quality and work efficiency of the individual. For example, dentists and surgeons might have the need to use computer while their hands are occupied which is not possible with standard computer mouse or keyboard. Also, people with certain types of disabilities (e.g. quadriplegia) are unable to use computers and are thus denied numerous benefits both in their rehabilitation and everyday life activities.
In the literature number of research articles can be found on the topic of hands-free computer interface for the disabled. These can be grouped based on several criteria, one of which is:

- systems based on physiological signals,
- systems that track movement of body parts and/or landmarks,
- systems based on voice commands.

The decision which system to use for particular individual is complex [1] and is based on number of variables some of which are: level of user disability, user preferences, user friendliness, learning curve and price.
Systems based on physiological signals are used when subject is totally paralyzed or “locked-in” due to medical condition such as Amyotrophic Lateral Sclerosis (ALS). Recorded physiological signals include electroencephalogram (EEG), electromyogram (EMG) and electrooculogram (EOG). EEG signals are generated by brain activity, while EMG signals are generated by contracting muscles and EOG signals are generated by moving eyes.
EEG based systems translate measured brain activity into appropriate control actions which reflect intentions of the subject. Although the concept has been present for number of years and numerous applications have been successfully demonstrated several important issues still remain [2]: EEG signals are error prone and can be easily contaminated, uncontrolled variability in timing and low bandwidth in direction *subject-computer*. Thus design of intelligent user interfaces is important for success of EEG based systems. Blinkertz et. al. [2] used Berlin brain-computer interface for actuated spelling via Hex-o-spell. The Berlin computer interface operated based on spatio-spectral changes in EEG signals during motor imagination. Additionally, machine learning algorithms were implemented to achieve higher quality feedback based on user specific brain signature. Hex-o-spell spelling interface combined probabilistic data and dynamic system theory to control character selection. Language model was used to adopt the character layout to reduce selection time. Reported typing speed results measured on two healthy subjects ranged from 2.3 char/min to 7.6 char/min. Obermaier et. al. [3] used Graz brain-computer interface to measure information transfer rates and examine how the number of different brain

activities (N) influences the results. The Graz brain-computer interface was based on classification of recorded EEG signals during N predefined mental tasks (with N_{max}=5) using hidden Markov models (HMMs). System was tested on three healthy subjects with best performance in terms of accuracy achieved for N=2. The accuracy decreased with increasing value of N. Information transfer rates demonstrated high intersubject and intrasubject variability. The highest recorded information transfer rate was 0.81 bits/trial (with 12 selections per minute).

EMG based systems are less error prone and are harder to contaminate with noise as compared to EEG based systems. Barreto et. al. [4] developed an interface for the disabled based on classification of facial EMG signals. One electrode was used to detect brain activity in the cerebrum's occipital lobe and thus provide control of ON/OFF switching. The system was tested for 2D control of pointer movement and execution of selection task (i.e. left mouse click). Thresholding was used to detect muscle contraction while pointer movement commands (up, down, left and right) were derived by means of real-time frequency analysis and Periodogram analysis. Authors tested the proposed system on multidirectional point-and-select task but reported only the measurement time (in average 16.3 s compared to 1-2 s with standard mouse). Chin et. al. [5] upgraded the system to incorporate video based eye-gaze tracking (EGT). EGT subsystem was used for dynamic positioning of the pointer while EMG subsystem was used for fine adjustments of pointer coordinates as well as issuing click command (and thus avoiding Midas-Touche problem associated with EGT devices). Authors tested device performance on the group of 10 healthy subjects and compared the results with two other test groups: one for EGT only system and one for standard mouse. Obtained results demonstrated higher measurement time for the proposed system (4.7 s) as compared to EGT system (3.1 s). On the other hand, accuracy of EGT/EMG system (0.14 errors/trial) was better then the one achieved by EGT system (3.98 errors/trial) and comparable to mouse error (0.01 errors/trial). Jung et. al. [6] combined different physiological signals (EEG, EMG and EOG) to enable computer access for severely motor-disabled subjects. The system was portable due to low power consumption and used three electrodes adhered to subject's forehead. Measured signals were amplified and noise was removed by filtering techniques (e.g. notch filter). Prior knowledge of frequency content of individual physiological signal enabled band-pass and high-pass filtering and thus signal decoupling was achieved. System was tested on simple click test where it proved its applicability. Authors noted that success rates remarkably improved after repetitive training.

The disadvantages of systems based on physiological signals such as high price, requirement for highly specialized hardware, low portability, complex and sophisticated signal processing algorithms led to development of systems in which computer access is provided by monitoring of subject's remaining motor functionality. Obviously, this approach is ineffective for totally paralyzed subjects. Arguably the most popular *"motion methods"* are video based methods. Betke et. al. [7] developed *"Camera Mouse"*, the system based on single camera that tracked user movements and moved computer mouse accordingly. The tracking algorithm was based on template matching via correlation and constant template updating. The system enabled tracking of user defined body landmarks (e.g. eyes, lips and thumbs). Testing was achieved with 20 healthy subjects and 12 subjects with some kind of motor disability. Authors used measurement time as performance parameter and concluded that in general the proposed system is two times slower as compared to standard mouse but presents portable and usable system for the disabled. Kocejko et. al. [8] designed computer interface system based on two (web) cameras mounted on user's glasses. The first camera was directed toward the user and was used to track eye movement, while the second camera was directed toward computer screen (marked with four LEDs) and was used to compensate for head movement. The system required calibration in order to establish mapping between eye positions and screen coordinates, and used longest line detection algorithm for obtaining pupil center coordinates. The device usability was demonstrated on healthy subjects with accuracy in strong correlation with proper longest line detection. Miyake et. al. [9] used real-time eye gaze estimation for computer control. The proposed method used single facial image acquired under ordinary light conditions to generate pointer movement. For its operation it required virtual reference point defined based on face feature (10 in total) motion between two consecutive video frames. The face features were tracked by condensation algorithm or particle filter. Improved performance was achieved by implementation of blinking detection algorithm. Authors tested the proposed method on simulated data and on experimental data with good results. Somewhat different method that still can be classified as video based (but worked in infrared spectrum) was developed by Chen et. al. [10]. The system consisted of three main parts: infrared transmitting module mounted on user's eyeglasses, infrared receiving module (consisting of 60 individual receivers) and main controller. Additional hardware was also used: tongue-touch panel for ON/OFF switching of infrared transmitters and laser pointer and buzzer as audio-visual feedback of current selection. The device operated in a way that infrared receivers were placed around the monitor, each one corresponding to one control action (e.g. keyboard key). The user would look at desired control wearing eyeglasses and thus illuminated corresponding infrared receiver. Testing was achieved on three healthy and three disabled subjects with good accuracy (above 94%) and measurement time under 5 s (adjustable). Some other video based approaches can be found in [11, 12, 13]. It is worth noting throughput value of vision based system (ViewPoint from Arrington Research) which used eye tracking by pupil and corneal reflection [14] measured by means of infrared camera focused on subject's dominant eye. For multidirectional point-and-select tasks obtained throughput values were (depending on selection technique) in range from 2.3 bits/s to 3.78 bits/s.

Although video based approach has low price, doesn't require any specialized hardware, has small dimensions and high portability they suffer from disadvantages inherent to video based techniques: sensitivity to lightning conditions, limited field of view, shadows etc. This prompted development of methods which track movement of subject's body part(s) using different sensors. As an example three different approaches are presented. Huo et. al. [15] introduced wireless tongue operated assistive device named Tongue Drive System. A small rare-earth permanent magnet was secured on the tip of subject's tongue and its movement was detected by an array of magnetic field sensors mounted on a headset outside the mouth or on an orthodontic brace inside the mouth. Effects of external magnetic field disturbances were minimized by reference electronic compass placed on top of subject's head (as far as possible from permanent magnet). During training phase principle component analysis was used to extract the most important signal features of individual commands and thus form cluster space. The k-nearest neighbor algorithm was used for classification purposes. The system was tested on healthy subjects with information transfer rate (ITR) of 2 bits/s and accuracy higher than 90%. Chen in his work [16] demonstrated application of magnetoresistive tilt sensors in human-computer interface. Two tilt sensors were place on user head by means of a headset. One sensor detected lateral head movement driving screen pointer in left/right direction while the second sensor detected vertical movement driving screen pointer in up/down direction. A touch switch was placed near subject's cheek and was activated by subject puffing his/hers cheek. The switch was used to trigger the device and execute drag, single click and double click commands. The device was tested on six healthy subjects and six subjects with quadriplegia. Obtained average accuracy was above 95%. Nunoshita and Ebisawa [17] designed computer interface device based on ultrasonic measurements of subject's head pose and dynamics. Three ultrasonic transmitters were attached to user's head while three receivers were placed around computer screen. Time of flight was used for distance calculation while phase difference was used for head tracking. System was tested on three male subjects with point and select task. The results demonstrated longer measurement time for the proposed device in comparison with standard mouse by factor of 1.12-1.35.

The third group of user interfaces is voice activated. They operate well in quite settings but are unreliable for noisy environments. They are also language specific (i.e. different voice commands for same action in different languages). Examples of voice activated user interfaces can be found in [18, 19], while their integration in more complex system is presented in [20].

Based on literature review we believe there is a need for simple, highly portable, accurate, intuitive and user friendly device which could be used by both healthy subjects and impaired subjects who retained some motor functionality (e.g. in the head-neck region). The device should be small in size and weight, require very simple calibration procedure and signal conditioning algorithms and operate without external (artificial) sources. The proposed inertial sensor based device (which we named *HeadJoystick*) satisfies all of the above conditions with the note that it's most significant drawback is high price (>1000 USD). By examining available literature lack of standardization in reporting of performance results for non-keyboard input devices can be observed. This makes difficult effective comparison of performance of different input devices. Introduction of ISO 9241-9 standard should eliminate this issue. Thus proposed device was tested on guidelines based on ISO standard as presented in [14, 21, 22] and results are presented accordingly.

The article is structured as follows. In section two experimental setup and procedures are described, and evaluation parameters defined. Section three presents and analyses obtained experimental results. Finally, some conclusions are drawn based on experimental results, and future improvements and research directions are proposed.

2 Methodology

Testing of the proposed system was done using multi-directional point-and-select task adopted from [21] which was based on ISO 9241-9 standard (*Requirements for non-keyboard input device*). Measurements and data collection were achieved using specialized software (developed in our laboratory in Visual C#). After completion of system testing each participant was asked to complete a questioner and thus provide user feedback for comfort assessment.

2.1 Test subjects

Twelve volunteers (10 male and 2 female) were recruited from faculty staff and students. All were everyday computer users (mouse and keyboard) with >4 h of computer usage per day and have never before used a hands-free pointer device. All participants were healthy with no prior cervical spine injuries which would interfere with normal execution of point-and-select task using our system. Participants age ranged from 21 to 35 years (mean 25.3).

2.2 Measurement equipment

The proposed system used commercially available Xsens MTx sensor and XBus Master [23] as seen in Figure 1.

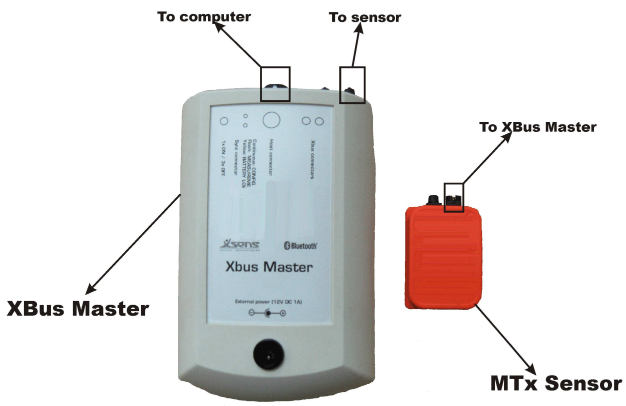

Fig. 1 – Inertial sensor and XBus Master

The sensor incorporated triad of accelerometers, gyroscopes and magnetometers and as an output provided 3D orientation with angular resolution of 0.05 degrees, static accuracy < 1 degree and dynamical accuracy (depending on movement) of 2 degrees RMS. Sensors were relatively small measuring 38 x 53 x 21 mm (W x L x H) and weighing 30 g. The XBus master is digital data bus with data processing capabilities (based on Kalman filtering) which can operate in one of two modes: wire mode (used in measurements) or wireless mode via Bluetooth (enabling high portability).
Sampling frequency in experiments was set to 100 Hz. The sensor which was positioned on top of subject's head was used to measure absolute head orientation (roll, pitch and yaw angles) and was secured in place by elastic harness which ensured snug fit and prevented sensor from moving during measurements. Sensor position and definition of head angles can be seen in Figure 2 and Figure 3 respectively. Please note existence of additional inertial sensor under the subject's chin. This sensor was used to test additional selection technique which, due to poor performance, was later abandoned.

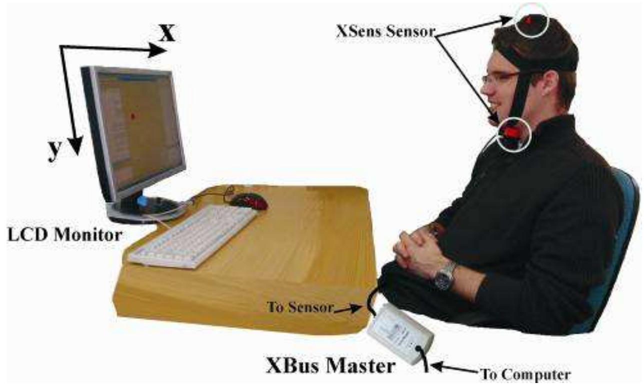

Fig. 2 – Measurement setup

Experimental testing was achieved using 20" wide LCD monitor measuring 42 x 26 cm, set to 1680 x 1050 pixel resolution. This yielded distance/pixel ratio of 0.025 cm/pixel. Test subjects were seated approximately at a distance of 70 cm from the monitor. As a referent input device Trust GM-4200 optical mouse was used.

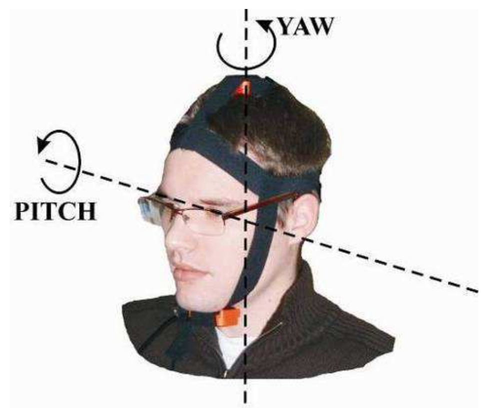

Fig. 3 – Definition of head angles

2.3 Performance parameter

The performance parameter used in our study was *throughput* [14, 21, 22]. It incorporates both the speed and accuracy of individual's performance of point-and-select task, and is relatively independent of task difficulty.
Throughput is defined as

$$Throughput = \frac{ID_e}{MT}\left[\frac{bits}{s}\right] \quad (1)$$

where ID_e is effective index of difficulty and MT is measurement time (time required to complete point-and-select task for specific target). Effective index of difficulty is defined by the following equation

$$ID_e = \log_2\left(\frac{D}{W_e}+1\right) \quad (2)$$

where D is the distance between center of home position and center of target circle, and W_e is effective target width defined as

$$W_e = 4.133 \cdot \sigma \qquad (3)$$

In Equation (3) σ is defined as standard deviation in selected target coordinates. The error rate (ER), defined as percentage of unsuccessful point-and-select tasks for particular test condition, was also recorded and later analyzed.

2.4 Experimental design

In order to determine main independent variables for the experiment three selection techniques were tested: time trigger, keyboard and sensor based technique (which we named "*jaw click*"). The purpose of the test was to examine feasibility of "*jaw click*" approach which was based on two conditions affected by subject moving his/her lower jaw: change in orientation of one inertial sensor with respect to the other and change in angular rate of turn of the sensor under subject's chin. The approach was tested on two healthy subjects. The obtained results depended on used pointer control method (accuracy: 48-84% and throughput: 0.41-0.5 bits/s) but were very poor. This, in conjunction with negative user feedback (frequent sensor movement and reliability issue) prompted us to eliminate the "*jaw click*" from further study, Thus, the main independent variable in our study was Input Technique which had six levels:

1.) Mouse with keyboard (MWK)
2.) Mouse (M)
3.) HeadJoystick with keyboard (HJWK)
4.) HeadJoystick with time trigger (HJT)
5.) HeadJoystick in pointer mode with keyboard (HJPWK)
6.) HeadJoystick in pointer mode with time trigger (HJPT)

In order to minimize learning effects, six Input Techniques were counterbalanced using 6 x 6 balanced Latin square as depicted in Figure 4.

The MWK and M techniques were included in the study to provide referent values for the proposed system and enabled validation of used experimental procedures and design through comparison of obtained mouse throughput. In the MWK technique subject used one hand to move the mouse and position the pointer over the target, while the other hand was used to press the spacebar and thus complete selection task. The M technique used mouse for both pointing and selection task. The proposed system was tested in four different *pointing mode-selection mode* configurations. The two pointing modes were: *Joystick* and *Pointer*, while two selection modes were: *keyboard* and *time trigger*.

Participants 1,7	1	2	6	3	5	4
Participants 2,8	2	3	1	4	6	5
Participants 3,9	3	4	2	5	1	6
Participants 4,10	4	5	3	6	2	1
Participants 5,11	5	6	4	1	3	2
Participants 6,12	6	1	5	2	4	3

Fig. 4 – Balanced Latin Square

In the Joystick mode, pointer could move in one of eight predefined directions (left, right, up, down, up-right, up-left, down-right, down-left) with two speeds depending on the current head pose in respect to neutral position (i.e. subject looking at the center of the screen with eyes straight forward). Small movements around neutral position were allowed and did not trigger pointer movement (i.e. *neutral zone*). The control space of *Joystick* mode is depicted in Figure 5.

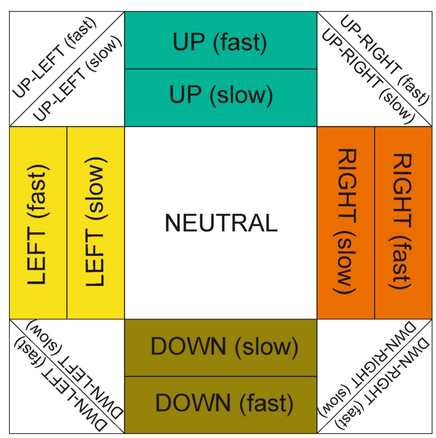

Fig. 5 – Joystick control space

It should be noted that limited pointer speed resulted in best case scenario movement time of 1.43 s and 1.78 s depending on target distance. In the Pointer mode subject's current head pose (pitch and yaw angles) was transformed into screen coordinates. In this mode pointer movement speed and direction were not predefined and depended only on user's current head pose and its rate of change. It should also be noted that there was no neutral zone in this mode.

The keyboard selection technique required the subject to press the spacebar to complete the selection, while in the time trigger technique user had to position the pointer inside the target circle and keep it there for 400 ms in order to complete the selection task.

Three additional independent variables were used: target circle width *W* (20 pixels, 60 pixels), home-target distance *D* (300 pixels, 420 pixels) and trial (1 to 16). The total number of trials was 4608 (12 test subjects x 6 input techniques x 2 target circle widths x 2 home-target distances x 16 trials), requiring in total 836 minutes of measurement (approximately 70 min per subject). It should be noted that larger target circle (60 pixels) approximately corresponded to Windows desktop icon size. Comparison of normal icon size and target circle sizes is depicted in Figure 6.

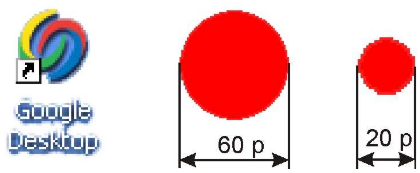

Fig. 6 – Comparison of icon and target sizes

2.5 Measurement procedure

Before the measurements, each test subject was briefed on experimental procedures as well as experimental goals and informed consent was obtained.

Test subjects were seated comfortably in front of a computer with measurement software running (Figure 2). The first step in all the measurements was system calibration in order to account for variations in sensor positioning for particular test subject. The calibration procedure required the user to look at three dots on the monitor (center, left and top of the screen) thus defining field of view and corresponding yaw (ψ_{CAL}) and pitch (φ_{CAL}) angles. Based on recorded angles and monitor resolution, pixel-to-angle ratio could be defined as

$$Ratio_x = \frac{Screen\_Width}{2 \cdot |\psi_{CAL\_NEUTRAL} - \psi_{CAL\_LEFT}|} \tag{4}$$

for *x* direction, where $\psi_{CAL\_NEUTRAL}$ is yaw angle recorded when the subject was looking at center dot and ψ_{CAL_LEFT} is yaw angle recorded when the subject was looking at left dot, while pixel-to-angle ratio for *y* direction was defined as

$$Ratio_y = \frac{Screen\_Height}{2 \cdot |\varphi_{CAL\_NEUTRAL} - \varphi_{CAL\_TOP}|} \tag{5}$$

where $\varphi_{CAL\_NEUTRAL}$ is pitch angle recorded when the subject was looking at the center dot and φ_{CAL_TOP} is pitch angle recorded when the subject was looking at top dot. The definition for pitch and yaw calibration angles is depicted in Figure 7. With known ratio coefficients and calibration angles any yaw-pitch angle combination could be transformed into screen coordinates (with different algorithms depending on pointing mode). After calibration procedure was completed, experimental measurements could begin.

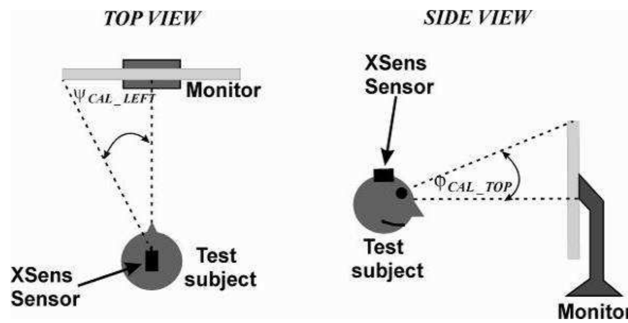

Fig. 7 – Definition of calibration angles

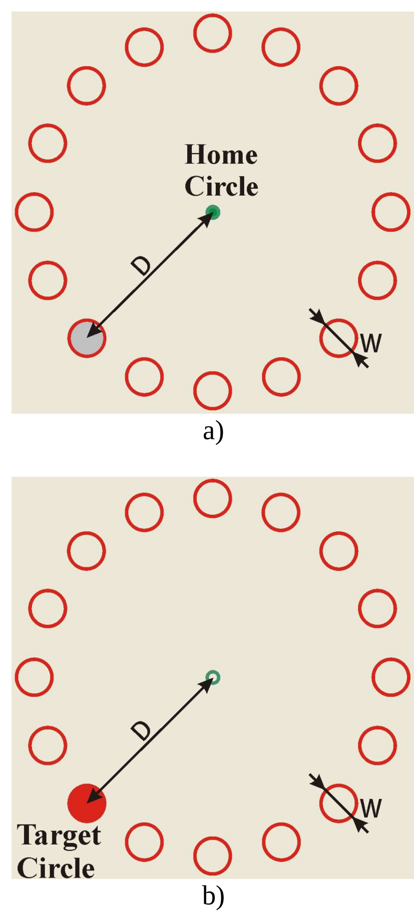

Fig. 8 – Multidirectional point-and-select task

At the start of every trial home circle was highlighted (green color; all other circles transparent) as shown in Figure 8.a) and the participant was instructed to position the pointer over the circle and select it (manner in which selection was achieved depended on current selection mode). Then, one of the target circles (in predefined order thus avoiding need for reflex response) became highlighted (red color; all other circles, including home circle were transparent) as shown in Figure 8.b). Test subjects were required to, as quickly as possible, position the pointer over the target circle (as close to it's center as possible) and select it. Then, the next trial followed.

After the measurement, each test subject was given two questionnaires to complete (one for Pointer mode and one for Joystick mode). The questionnaires consisted of twelve questions each (Table 1), and were designed to provide user feedback on device comfort and performance.

Table 1 – Assessment Questionnaire

No.	Question
1.	Would you like to use HeadJoystick device?
2.	General impression compared to the mouse?
3.	Neck fatigue
4.	Eye fatigue
5.	General comfort
6.	Pointing speed
7.	Target selection
8.	Accurate positioning
9.	Physical effort
10.	Mental effort
11.	Movement smoothness
12.	In general, the device usage was…

3 Experimental results and discussion

3.1 Performance parameters

In order to validate our experimental design and procedures, first the throughput parameter for mouse Input Techniques was compared to throughput values found in the literature [14, 22] and was found to be in agreement. Figure 9 depicts throughput mean values and their standard deviations for six input techniques. ANOVA testing showed there was a significant effect of Input Techniques on throughput ($p<.0001$). The largest throughput was recorded for computer mouse with MWK measuring 4.4 bits/s and M measuring 3.8 bits/s. Better performance of MWK compared to M could be explained by user overconfidence while using M and better positioning (higher precision) in MWK since target selection was achieved by means of second hand, but this phenomena needs to be studied further. For the proposed system mean throughput values ranged from 0.918 bits/s to 1.927 bits/s depending on the pointing and selection techniques. Closer examination of Figure 9 revealed that change in pointing technique resulted in larger difference in throughput than change in selection technique. It is worth noting that in joystick mode pointer speed was limited to only two levels (75 pixels/s and 225 pixels/s) and better performance might be achieved by increasing number of speed levels as well as maximum speed. The best performance in terms of measured throughput, HeadJoystick device had in pointer mode with time trigger selection mechanism. This is still 49% lower compared to traditional mouse technique (M).

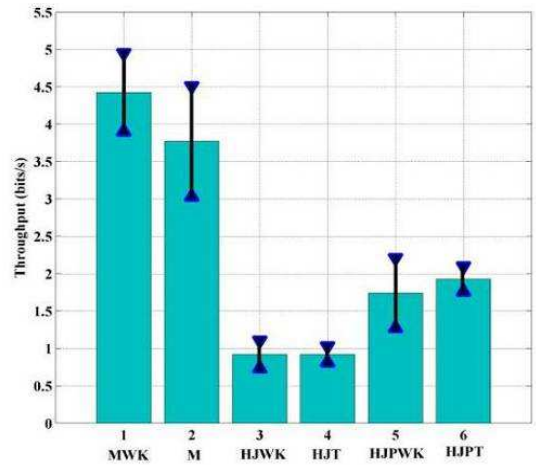

Fig. 9 – Mean throughput values with standard deviations

When making this kind of comparison user experience with certain device should be considered. Thus, it should be noted that all participants used the proposed system for the first time and were only allowed 5-10 minutes of usage before measurements (while they were experienced mouse users). In order to emphasize influence of user experience on measured throughput, we recruited one person (female, 55 years) with very little mouse experience (used mouse only several times with total usage time <10 h) and redid the experiment for MWK and M techniques only. Obtained throughput was 1.857 bits/s for MWK and 2.214 bits/s for M technique, which is lower by 58% and 42% in comparison to respective results of mouse expert group. While these results are by no means conclusive they strongly suggest that considerable improvements in throughput of our device could be expected once users become more proficient in its usage. Table 2 presents comparison of throughput values for different pointing devices found in literature [14, 21, 22]. Note that throughput for the mouse is given in range values due to different values found in different studies. Also ViewPoint as well as HeadJoystick throughput depended on selection techniques.

Table 2 – Comparison of throughput for different pointing devices

Device	Throughput [bits/s]
Mouse	3.7-4.5
Trackball	3.0
Joystick	1.8
Touchpad	2.9
ViewPoint (eyetacker)	2.3-3.7
GyroPoint (gyroscope based device)	2.8
RemotePoint (remote isometric joystick)	1.4
HeadJoystick	0.92-1.93 (1.1-2.8)*

Asterix symbol for the HeadHoystick device indicates throughput values obtained on limited sample group and limited test conditions after some improvements were implemented. This will be discussed in more detail in conclusion.

Since throughput combines both the speed and accuracy of point-and-select task, a better insight can be achieved by examining measurement times and error rates. Mean measurement times with standard deviations for all six input techniques are depicted in Figure 10, while Figure 11 depicts input technique error rates. Mouse input techniques had the lowest measurement time with M measurement time lower by 11% compared to MWK. That, in conjunction with better accuracy of MWK, attributes to possible explanation (stated earlier) as to way MWK throughput is larger than M throughput. Closer inspection of Figure 10 and Figure 11 reveals that joystick mode had better accuracy in comparison to pointer mode but at expense of much higher measurement time (which could be partially explained by already mentioned limited joystick speed). In post-measurement interviews, two interesting observations which could explain lower accuracy for Pointer mode and larger measurement time for Joystick mode surfaced. In Joystick mode number of participants noted that there was no (visual) feedback as to where they were in control space defined in Figure 5 (i.e. if they were in neutral zone, what pitch and yaw angles were needed to move the pointer in up-right direction for example), which resulted in number of target re-entries increasing measurement time. Thus, visual or some other type of feedback mode is needed in the future (i.e. some kind of *movement radar*). In Pointing mode participants noted pointer jitter while they were trying to keep the pointer inside smaller target circle.

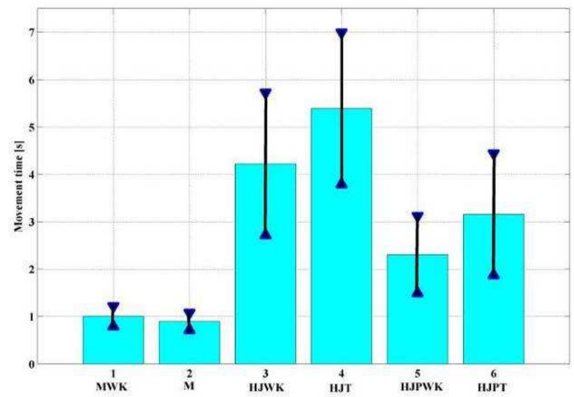

Fig. 10 – Mean measurement times with standard deviations

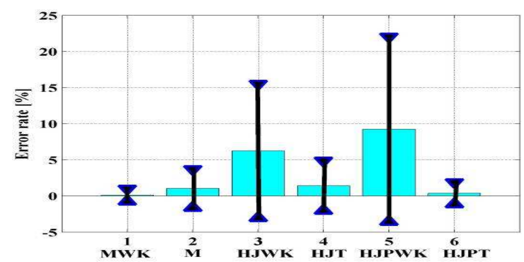

Fig. 11 – Mean error rates with standard deviations

This could be explained by smaller calibration angles for particular subject resulting in higher pointer sensitivity to head movement or head tremor. In order to reduce this effect we propose to implement standardized calibration angles depending on user-monitor distance and/or low pass filtering of pointer coordinates. Error rates in time trigger mode were result of limited time frame in which user was required to make the selection (4 s for pointer mode and 8 s for joystick mode).

3.2 Questioner results

Questioner mean results along with standard deviations are depicted in Figure 12 and Figure 13 for Pointer and Joystick mode respectively, where 1 represents the lowest possible score and 7 the highest possible score. These results should be analyzed while keeping in mind that this was participant’s first encounter with the proposed system.

Obtained results are similar for both pointer techniques with Pointer mode in slight advantage. Joystick mode performed better in terms of target selection and positioning as well as movement smoothness (Questions 7, 8 and 11), while pointer mode performed better in all other categories. It is encouraging that participants found the system not to be physical and mentally demanding and didn't cause eye and neck fatigue.

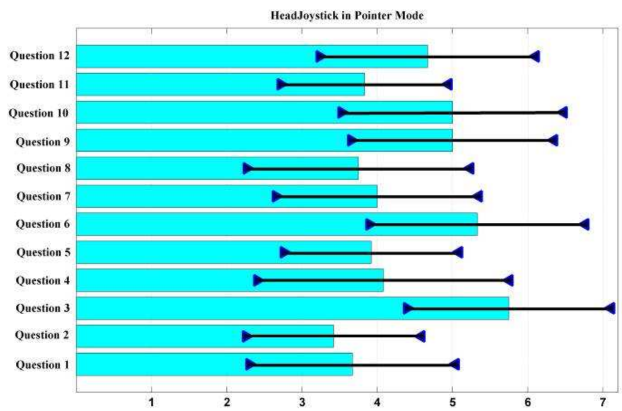

Fig. 12 – Questionnaire results for HeadJoystick in Pointer mode

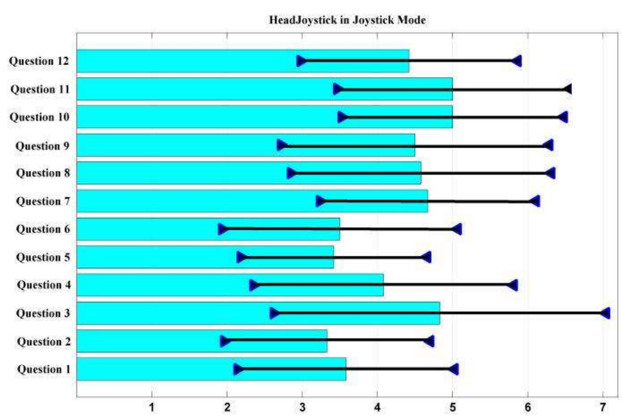

Fig. 13 – Questionnaire results for HeadJoystick in Joystick mode

4 Conclusions

The paper presents initial study evaluating performance of a novel pointing device. The study is based on experimental recommendations found in [21]. Two pointer and two selection techniques were tested and compared to two mouse input techniques. HeadJoystick device showed best performance in Pointer mode with time trigger mechanism measuring throughput of 1.927 bits/s (with mouse input technique measuring 3.8 bits/s). Keeping in mind this is the initial version of the device and that participants never used the system before (significant performance gains are possible as demonstrated on simple example), we believe the results to be promising and justify further research. User feedback was also positive. Participants reported no or low physical and mental effort, as well as low eye and neck fatigue. They commented positively on system user friendliness and operational simplicity.

Based on user feedback four improvements were implemented: 1) real-time sensitivity adjustment, 2) real-time low pass filtering with adjustable cut-off frequency, 3) simple motion radar for Joystick mode providing visual feedback, and 4) higher maximum pointer speed in Joystick mode. These improvements were tested on limited test group (4 subjects) and for limited test conditions (keyboard selection only) with intention of examining possible benefits. The obtained average throughput values were 1.1 bits/s (min. 0.85 bits/s, max. 1.6 bits/s) for Joystick mode, and 2.8 bits/s (min. 2.13 bits/s, max. 3.64 bits/s) for the Pointer mode. Taking into account larger user experience, we believe these results validated implemented improvements as well as the whole inertial sensor pointer concept with results comparable to other pointer devices (even with the mouse).

In the future we intend to implement further improvements as well as refine already implemented ones. Future improvements could include: calibration angle standardization, automatic sensitivity adjustment, automatic adjustment of filter cutoff frequency, better suited visual and/or audio feedback (i.e. *motion radar*), experimenting with higher maximum speed in Joystick mode with finer granularity and new selection techniques better suited for the disabled (e.g. EMG based techniques). Application of different sensors (e.g. Shake [24]) is planned to determine best possible solution in terms of sensor performance, price and portability. Also we plan to test our system on the disabled subjects once all of the improvements are implemented.

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