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Exploring EMG gesture recognition—interactive armband for audio playback control

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***Abstract*—This paper investigates the potential of using an electromyographic gesture recognition armband as an everyday companion for operating mobile devices in awareness-requiring contexts and suggests the fields, in which further developments are advisable. The Myo armband from Thalmic Labs is a fully functional motion controller, based on gesture recognition through EMG muscle sensing. The device has been applied for audio control, and the usability and relevance of the gestural interaction have been examined. Participants were asked to operate on a recording while cycling, and a reference group performed similar task in leisure context. The gathered answers suggest decent potential of gestural interaction manner for environments requiring high visual attention, eg. driving or cycling. However, the current state of the solution acts in too sensitive way, as processing numerous misinterpreted gestures highly decreases the system's usability. Moreover, gestures employed are perceived as too apparent and intrusive for social interactions.**

I. Introduction and Related Work

NOWADAYS, mobile devices are common everyday companion for various types of activities. However, in some of those contexts, the user's attention shall not be drawn towards the device operation, maintaining the control almost unnoticeable, both for the user and the environment. Therefore, various interfaces are being developed to meet those expectations.

Eyes-free Interface Technology

While mobile and wearable computing have been rapidly growing fields in the recent years, the approaches towards user interaction were dominated by vision-based techniques. However, restricted input and output capabilities of mobile devices, as well as limited screen space cause those approaches to be of a reduced usability [1]. Moreover, the visual perception of information is likely to be disadvantageous or even intrusive due to number of factors, such as: 1) *Competition for Visual Attention* - crucial in multiple mobile contexts eg. driving, running, cycling; 2) *Inconvenience* - as using the display requires the user to reach the device from a pocket or a bag; 3) *Technological Limitations* - such as reducing the battery life or the screen being illegible in bright sunlight [2].

Therefore, multiple interaction techniques employing senses other than sight have been developed in recent years. The most popular approaches make use of speech and gesture as the means of communication with the system [3]. Acoustic and haptic modalities have been adopted for assisting the interaction with mobile devices, both in terms of feedback and command, emerging the branch of eyes-free interfaces.

The most classical approach uses camera-based gesture recognition [4]. While real-time image processing and gesture recognition is no longer a challenging issue, the attitude still posses several constraints. The system intended for everyday use would need to be robust against environmental noise and obstructions of vision range, require minimal or first-use calibration and analyse comprehensible set of gestures and react with minimal delay. Moreover, a huge issue is connected to lightning conditions required by the system, which are out of control for rapidly changing environments. An attempt to bring such solution into practice was performed by Akyol et al. [5] for automobile use of acoustic messages. However, the necessity of assembling a complex camera-based setup makes this approach inappropriate for mobile scenarios.

An insightful endeavour towards applying gestures to audio control for on-the-go contexts was performed by Brewster et al. [1]. The study shown that metaphorical gestures are an intuitive and efficient way of interacting with an MP3 Player. However, the presented solution employed a device that the user was to swipe his finger at, therefore not solving the issue of inconvenience of hand-occupying device. A related solution was proposed by Zhao et al. [2], employing touch-input and auditory feedback for the purposes of menu browsing. This concept has been further explored by Kajastila and Lokki [6], providing further insights on menu operation using wii-like controller for eyes-free operation.

User Experience

The technological means of control are not the only challenge in designing appealing mobile interaction. It is the user experience and the emotions it brings that would make the novel interface become an everyday companion. Therefore, the social and behavioral aspects of operation are the essential issues to be addressed. Yi et al. [7] present an extensive analysis of key factors determining typical user motivations for using eyes-free interfaces. Apart form technological limitations mentioned in [2], these are the effort and social reception of the performed actions which significantly affect the system perceiving. Hence, the users indicated that it is desired to obtain low perceived effort and entertaining manner of operation. Moreover, the users specified a strong need for the manner that would not interrupt social activities or cause anxiety. The command over the device shall be organised in a way that would not draw undesired attention of the people in the nearest environment, which is the challenge that speech-recognition interfaces fail to successfully address [8] [9]. Those concerns are especially crucial in on-the-go scenarios of mobile device operations. Further, wireless and hands-free devices are desired, employing gestures with little human-to-human discursive meaning and being difficult to misinterpret [10].

EMG Gesture Controllers

The above-mentioned requirements may be met through employing gesture-recognition system that would enable to perform subtle and discreet movements, with minimal attention required. The technology which is capable to offer that functionality is an electromyographic sensor. EMG can convey information about muscle electrical activity, which could be applied for designing intimate mobile interfaces. An extensive study on the capability of this approach in terms of social-acceptance and user perception has been performed by Constanza et al. [11]. However, the system used, while offering satisfactory and promising interaction pattern, maintained of a hardware that was highly inconvenient through the necessity to apply electrodes on the users' bodies.

The most recent commercial solution of an appealing EMG controller have been delivered by Thalmic Labs, the Myo Armband [12]. The device consists of mutually aware set of electromyographic electrodes. Moreover, the device is equipped with 3D gyroscope, 3D accelerometer and a magnetometer for extended movement analysis. The band communicates via Bluetooth connection and enables controlling systems using set of predefined gestures. The precision and capability of the solution have been examined during the evaluation of the band for musical interaction application [13].

In our study, we explore the potential of gesture-capturing armband for the purposes of everyday interaction, using the case of audio playback control. The research aimed to verify whether EMG-driven solution is truly capable to meet the requirements of the subtle and convenient interaction, while maintaining sufficient precision and resistance against misinterpretations and environmental noise. The armband has been tested in two different context - one while performing moderately attention-requiring activity and the other in leisure context.

II. System Evaluation

In order to consider possible application of the system for everyday purposes, several criteria must be taken into account. The examined solution of an armband shall perform as an efficient tool for playback control, offering the desired user experience. Therefore, we decided to investigate following questions and concerns:

- establishing whether the Myo armband can perform as efficient audio controller,
- assessment of the usability of the gesture-based operation manner,
- examining the perceived effort and attention needed for Myo operation,
- inspecting the risk of performing undesired action due to gesture misinterpretations,
- studying social perception and emotional comfort of the gestural interaction,

Experimental Setup

The armband was configured to control a simple audio player. For this purpose only EMG sensors was used. The experimental setup employed three gestures to be interpreted: 1) *double tap* - resulting in play/pause toggle, 2) *wave in* - for switching to previous file/rewinding the recording 5 seconds back and 3) *wave out* - for switching to next file/rewinding the audio 5 seconds forward. These gestures were chosen because the device is excellent at recognizing them. The gestures are presented in figure 1.

Fig. 1. Gestures used in system: left - double tap, middle - wave in, right - wave out.

Prior to the test, the Myo armband was calibrated for the user and quick introduction was given. Then, first task for evaluation was introduced. The player was turned on into music preset - so the song switching gestures were made available. Each user was asked to operate the player for a while, pausing and playing songs and switching between them.

Following, the main podcast-based task was introduced - the player was preset in a way that rewinding became assigned to wave in/out gestures. The user was briefly introduced to the topic of the 12-minute long podcast on airplane crew cooperation [14]. The users were asked to listen to the recording and establish the answers to four content-relevant questions. The task was not time-limited and the users were encouraged to rewind or pause the recording if the find it necessary.

1) Scenario A - cycling activity: The users were asked to perform the task while cycling around the park. In such setting, additional muscle activity is present due to the necessity to control and steer the bicycle and overcome obstacles. Further, the issue of competition for users' attention and ease of control is emphasized. Moreover, the context enables analysis of the system's sensitivity towards noise and whether non-intended gestures are recognized. The setup described is depicted in figure 2.

Fig. 2. Setup used in bicycle scenario.

2) Scenario B - leisure activity: The control group were asked to perform the same task in leisure setting in a cafe. This scenario highlights the aspect of social perception of interaction and enables comparison for the assessment of the undesired gesture recognition influence on the usability (Fig. 3).

Fig. 3. Setup used in cafe scenario.

After completing the task, users were asked to fill-in System Usability Scale [15] and NASA TLX [16] questionnaires. Further, a wider post-study interview was performed. Participants were asked to share their views on the following issues:

- whether the system is conducive for everyday use,
- whether the gestures are intuitive and convenient,
- whether the system performed as desired and what problems were determined,
- to describe their feelings and perceived effort,
- whether they liked the system operations,
- to mention other contexts of potential use,

and encouraged for some free discussion about the tested device and their experience.

III. Results

The experiment was performed on a group of $N = 11$ participants, of various age and gender. Each participant took part in a single scenario - 7 participants in scenario A and 4 participants in scenario B. All of the participants from scenario A performed the activity on a sunny day between 12 and 16 PM. The assessment was performed based on the questionnaires answers and the interview commentary provided by the users.

A. Scenario A - cycling activity

Overall, the cycling task was rated as less challenging than the leisure one, with the exception of perceived temporal demand. However, participants felt less successful with fulfilling the task requirements. Averaged results of NASA TLX [16] task analysis are presented in figure 4.

Quantitative analysis of system usability using System Usability Scale [15] brought an average score of 69,64 points (STDEV 13,18), with the range of gathered scores between 47,5 - 80 points. This result suggests moderate usability, which comprises with qualitative analysis of the interview answers.

Users performing the cycling task appreciated lack of reaching the device out of a pocket. The gestures applied were commented as intuitive and easy to learn, and have been perceived as non-intrusive. The most significant drawback of the system was the tendency for gesture misinterpretations - the users complained that numerous undesired operations were recorded by the armband while steering the bicycle, especially while riding on rough road surfaces. Users felt lost, as multiple actions were performed one after another with no clear feedback on their sequence. Users commented: *Once I got into bumpy road, it messed up totally. I lost track of the podcast as it paused and resumed randomly. Every time I wanted to take a sharp turn left, it rewinded the recording*. On the other hand, the users appreciated that the operation of the recording requires relatively low attention and they can keep their vision focused on the road - *It was cool not to have to slow down or stop to safely operate the recording*.

Concerning the experience of armband operation, the participants stated that they feel confident with operating the device, does not feel ashamed or embarrassed using the device. However, some users commented that the gestures might be misinterpreted as turn signifying in traffic contexts. Multiple users shared the view that the device might be a convenient companion to control audio during driving - where the chance for undesired gestures is reduced, while the advantage of maintaining the sight on the road is even more significant. Yet, the same users confessed that they are not willing to use the device while on foot, as they believe it would misinterpret common gestures and might become inconvenient during social interactions, especially while not covered by the clothing.

B. Scenario B - leisure activity

Surprisingly, the task was perceived as more effort-demanding and more frustrating during operation in the leisure environment, while the users rated themselves more successful. The detailed analysis of the task effort measured is depicted in figure 4.

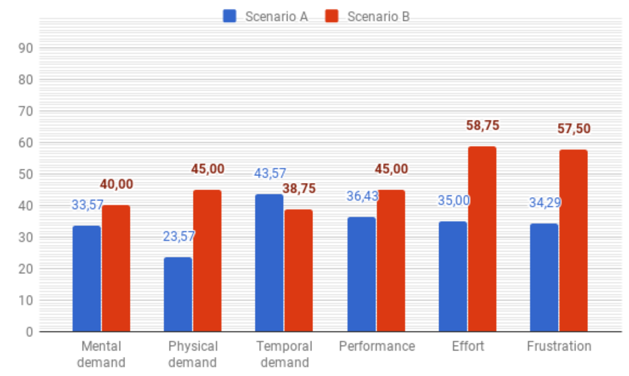

Fig. 4. NASA TLX Results - Scenarios A and B compared.

The system usability measured provided the average score of 71,25 points (STDEV 35,38), with the range of gathered scores being 20-98. The spread between assessments is significant, as issues connected to device calibration highly affected the operation manner for individual participant. It were the anatomic factors which seemed to be significant for proper system setup, as similar problems were encountered for different applications, such as [13]. Therefore, the score calculated on basis of median results seem to depict this assessment more accurately, providing the score of 82,5.

The most significant difference in regard to cycling scenario is the number of misinterpreted gestures reported - in the cafe environment undesired actions are less significant and limited to other movements performed by the user. The set of interaction gestures was commented as intuitive, while being easily mis-performed during common movements - eg. holding a mug, grabbing items. Moreover, some users felt uncomfortable when made to perform a particular gesture multiple times, which drawn attention of other people in the room. The users commented: *I feel quite weird sitting here and waving a hand to myself.*; *I might use it at home, while cooking or reading in my couch, but I don't feel alright with hitting the street with it.* Asked about other contexts of use, they suggested using the armband during jogging, cycling and driving.

The general impression from all participants consisted of the device being too sensitive and performing a lot of undesired operations. A group of 7 users reported that they do not feel comfortable enough with system operation to use it in public, as they would feel embarrassed. Moreover, when informed about the price of the device, majority of users stated that they would not spend that much money, even if the device were applied for contexts suggested by themselves. On the other hand, supporting phone and audio control while driving was the most frequent idea for possible application of the device.

IV. Discussion and Future Work

The performed study clearly highlights several drawbacks of the current state of the technology. While the EMG-driven armband offers satisfactory precision and technological capability [13], it does not offer the desired user experience. The metaphorical gestures chosen by the Myo designers act properly, offering decent level of intuitiveness and enabling quick learning of system principles. However, the social reception of system control draws too much of an undesired attention and may cause anxiety during interacting with others, which is a huge drawback when concerning the device as possible daily companion [7] [2]. Therefore, further improvements in recognition of more discrete gestures shall be applied to enable convenient control of the device in social contexts.

Furthermore, the task assessment shows that using the device is seen as more demanding when the eyes-free interaction manner is not a clear advantage. Occasional need for performing a particular gesture multiple times, combined with quite apparent and explicit movements is perceived more demanding than habitual on-screen operation [17]. This reception results in extended frustration while the device is misoperating, as a well-known alternative naturally arises. However, the effect is no longer present when engaging the sight is clearly unfavorable [18].

A drawback reported to be the most frustrating during armband operation was the excessive sensitivity, causing numerous undesired actions to be performed unconsciously. Misinterpretations turned out to be the most significant flaw noticed, highly affecting the comfort of use - while the users rated the concept as interesting and worth exploring, they were not willing to use the device in the current state due to difficulty of maintaining control over its reactions.

In terms of improving usability, a new concept for decreasing the number of redundant tensions being processed is necessary. Reduced sensitivity is clearly not a suitable solution, in presence of the need for more subtle gesture recognition. Hence, deeper investigation is advised to facilitate greater control over the armband. One of the possible approaches employs using an interpretation window triggered with a highly unique gesture. However, such method requires extensive investigation both in terms of efficiency and the effort and social - related criteria [19] [7].

Analysis of the gathered results enables to observe that the armband performs efficiently when used with decent focus on its operation. Therefore, it might be advantageous to apply the device as a controller in direct contexts, such as interacting with large displays [20] or for controlling rapid visualisation techniques for dynamic real-time process imaging [21] [22] [23] [24] [25] [26] [27], semi-automatic data analysis [28] [29] and crowdsourcing analysis of industrial images [30] [31]. High precision of the movement processing may be employed for mapping the movements of users' forearm onto other kinds of motile devices, such as drones and robots [32]. Further investigation is advocated in the field of ergonomics and potential consequences of long-term operation of the armband, as mid-air interaction pose several challenges in terms of arm fatigue, as signified in [33].

V. Conclusions

The concept of an armband is a successful endeavour towards providing an accessible EMG gesture-recognition controller, having several interesting and efficient applications. However, the examined device poses additional challenges to its users in terms of everyday use. Excessive actions performed due to misinterpreted muscle activity highly affect the system's versatility and decreases the comfort of use. Nevertheless, the armband presents enormous potential for developing eyes-free interactions, employing exceptionally capable technology for gesture recognition. Further efforts for designing more subtle and restrained user experience are necessary for providing efficient and convenient eyes-free interface, suited to support mobile contexts where vision-awareness shall be drawn towards other factors. The proposed solution is promising in terms of alleviating users' problems with operating screen-based devices in contexts where it is unfavorable, but also create an engaging and enjoyable experience of operation.

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