Improving Usability, Safety and Patient Outcomes with Health Information Technology
F. Lau et al. (Eds.)

doi:10.3233/978-1-61499-951-5-436

Smart Home Interactions for People with Reduced Hand Mobility Using Subtle EMG-Signal Gestures

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Abstract. Smart home technology is receiving significant attention. This is largely in response to an increase in the size of demographic those who require assistance due to reduced mobility, in particular, older adults. Smart home technology enables the assistance individuals with limited mobility need for their daily routines: these limitations can be addressed using modern ambient assisted living technologies. In particular we discuss the benefits of using electromyography (EMG) sensors to capture gestural input that would normally be difficult to sense in the absence of such sensors. With EMG, we can provide user control of a smart environment through the use of gestures based on muscle activity of the hands. This paper will focus on presenting the benefits of EMG technologies that can potentially assist individuals with hand mobility issues. We will describe the current state of EMG sensory technologies and their role in shaping gesture-based interaction techniques. We present our approach using such EMG signals and demonstrate their value in a smart home scenario. Finally we introduce the concept of subtle EMG gestures and build a better understanding of how we might improve accessibility for those with limited upper limb motion.

Keywords. elderly assistance, assistive technology, electromyography, home care, gesture-control

1. Introduction

Accessibility generally refers to the design of products, devices, services, or environments for people who experience some physical or mental limitations [1]. The issue of accessibility is the most prevalent among older adults [2–4], with major contributors to limited accessibility being ageing and long-term or chronic conditions caused by injury and illnesses [5–7]. These limitations and conditions affect cognitive, perceptual, and motor abilities. Motor issues connected with shoulders, hands, forearms, and wrists joints coupled with low flexibility of both joints and muscles as well as their weakness, may all result in poor manual dexterity, slower motions, reduced strength, reduced fine motor control, decreased range of motion, and most importantly, reduced grip force of hands and fingers[8, 9]. We will hereinafter refer to these hand limitations as hand mobility issues despite the extent of their severity.

Many countries are experiencing a huge demographic shift, where the proportion of the older adults is rapidly increasing. According to many credible global organizations (e.g., United Nations and WHO), the global population aged 60 and over has tripled since 1946 and 1965. It is expected that this population group will continue to grow significantly in the future. Nearly 21% of world population will be over 60 years old and is projected to more than double its size in 2015, reaching nearly 2.1 billion by 2050 [43]. It is widely accepted that significantly more work is needed in order for our society to make a smooth transition to accommodate this demographic shift.

A wide range of sophisticated technologies are being produced within the realm of smart homes (e.g., remotely programmable automated functions and systems). The key aim of a smart home is to improve comfort, energy savings, and security for the residents in the house. Due to these significant benefits, smart homes are endorsed by a variety of credible organizations (e.g. World Health Organization, United Nations, etc.) [10]. This is presumably because a growing rate of ageing population cannot be supported by simply increasing the number of caregivers [10]. Human Computer Interaction (HCI) as a field of research focuses on designing the interaction interfaces between people and computers and plays an important role in the studying of smart homes. Ambient Assisted Living (AAL) as a branch of the Human Computer Interaction (HCI) field specifically focuses on the upcoming challenges and objectives of providing those living independently with various supporting technologies. We would like to consider potential methods to accommodate individuals with limitations in using smart home technologies.

2. Background

2.1. Hand Gestures

Generally, users utilize movements of hands, head, face, and other parts of the body to interact with virtual objects. Furthermore, studies have investigated how older adults use gestural inputs during their interactions with technologies [11–16]. Research supports the use of hand gestures over other interaction methods with respect to learning time. Not surprisingly, hand gestures have become one of the most preferred input methods [17]. Hand gestures can offer a fast and effective medium for controlling and communicating with intelligent devices. Additionally, robust and effective gesture recognition technologies allow us to control a variety of applications with articulated prosthetic hands [18], a mobile device, and intuitive game interfaces [19].

Among many other hand gesture techniques, soft computing (software development) techniques offer new perspectives on the application of electromyography (EMG) signals in the control of devices in a smart home environment. EMG signals refer to biological signals produced by the neuromuscular system when users perform any muscle movements (e.g., contractions). It allows effective extraction of informative signal features in case of high interference between useful EMG signals and strong noise signals [20]. There are two types of EMG recording electrodes: surface [21] and intramuscular [22]. While intramuscular sensors require a needle electrode to be inserted directly into a muscle, surface EMG sensors record muscle activity from the surface of the skin and require only direct skin contact in the region of the specific muscle(s) [23]. Moreover, both commercial and research prototypes have demonstrated a great potential for machine learning to decode surface EMG signals and enable natural gesture recognition [24–27]. Compared to their original bulky form (e.g., Biopac MP150 EMG system with many electrodes) [28], modern EMG sensors have progressed significantly. One of the most recent EMG sensors, the MYO Armband designed by Thalmic Labs, is a wireless armband that contains 8 medical grade stainless steel EMG sensors and a highly sensitive nine-axis IMU [27]. Although the form is quite simple, it is a very powerful tool for hand gesture recognition as well as arm movement tracking. Moreover, MYO has a set of built-in gestures designed for commercial purposes. The goal of the MYO is for easy and comfortable interaction with technologies using hand gestures, which fit our research purposes quite nicely.

2.2. Smart Home for Older Adults

While population is ageing at such a growing rate, we must prepare for the potential financial impact we face in caregiving costs. Meanwhile, smart homes are gaining popularity worldwide. Health-care institutions and medical facilities are particularly interested in helping people stay home longer, not only to minimize costs, but also to support older adults' independent living [29]. Living independently without any assistance can be physically and psychologically difficult, while living with the support of smart home technology (e.g., biological data monitoring with a movement sensor) will likely provide comfort to older adults, their family, and caregivers. Constant monitoring of the physical and mental state of the older adult should allow family and caregivers to be aware of any changes that he/she displays (e.g., the fridge door has not been opened for the last 12 hours, indicating an older adult is not eating). Remote health monitoring is a central component in the global vision of the smart home [29]. An additional category of applications is meant to facilitate independent living and provide remote seamless control of the environment for those with mobility issues. [30].

3. Applications

Many studies have been conducted to test the abilities of the Myo Armband for both medicine [31, 32] and human-computer interaction (HCI) [33–35].

Gestural interfaces in HCI based on EMG recognition have produced a range of applications for controlling smart home devices [36], mobile devices, wheelchairs, prosthetic robotic hands, and mobile robot navigation. To navigate a wheelchair in a real indoor environment, Moon et al. [37] for example, controlled an electric-powered wheelchair left, right, and forward with a corresponding elevation of shoulders. Further, robotic arm manipulations and robot navigation control systems have shown their potential in various studies using different EMG configurations [38–41].

In bio-medical engineering, EMG sensors are frequently used in prosthetic amputee rehabilitation applications to enable trans-radial hand amputees to regain a significant portion of their lost-hand functionality; using robotic hand prostheses [42]. This area of research specifically relies on the precision of the EMG data obtained from the sensor attached to the amputated limb. NinaPro, a well-known public database, contains datasets of jointly recorded surface EMG signals for predefined sets of gestures. Their goal was to establish scientific benchmarks to test for movement recognition and algorithms for force control.

Abduo et al. investigated the MYO Armband accuracy compared to the NinaPro database to find out whether the MYO can be used as a cheaper alternative for the prosthetic hand EMG sensor and build a generic extendable surface EMG interface, namely, an open source solution that can be used to further study the performance of various EMG sensors [42].

4. Motivation & Research Problem

The primary motivation behind this research is to understand, and ultimately, support the older adults, specifically when they face physical restrictions in their everyday lives. The ageing population might put an unfortunate strain on younger generations seeking to care for the older population (e.g., nearly a half of the Canadians aged 15 and older give care to some of their family members or close people [44]). Therefore, we suggest that applying smart home technologies and improving the seamless control of the smart environment via hand gesture-based interfaces might ease the difficulties caregivers face. Smart home technologies can be employed in both homes and hospitals to facilitate care and protect older adults' independence. Smart homes present a great potential to maintain users' well-being, quality of life, and confidence, when designed and used properly.

Although, the hand gesture-based interactions are common in HCI and represent a reliable interaction modality for the smart home environment, the majority of studies often focus on gestural input engaging young adults, leaving a wide gap between the young designers' personal experience and the experiences of the older users [17] and their aptitude characteristics which implies having any hand mobility issue. Currently existing and studied EMG-based hand gestures are designed without taking corresponding measures to address the physical limitations. Clearly, such studies are needed to employ various technologies to facilitate older adults' lives. Myo Armband is a good example to illustrate the issue, since using the device, we believe, introduces two main problems a senior population might face when using it: a) Existing built-in hand gestures may induce arm fatigue quickly, even for younger users, and, b) People with motor limitations or dysfunctions might find it hard to perform such gestures.

4.1. Existing Technical Limitations

Apart of the design we draw three major limitations using the EMG devices. Firstly, a sensitivity level is highly hardware-dependent and is defined by the frequency rate: the number of sensor measurements made per second. Secondly, machine learning models to process raw EMG data and train the system to recognize specific patterns as needed. The models and algorithms have different properties so it is very important to employ the algorithms which best suit for the problem, however, again, the accuracy thoroughly depends on a hardware that is used. Lastly, studies show that nearly perfect performance (95% to 98% rate of success) can be achieved when using the suitable machine learning methods [45–53], however, weaker or physically limited muscles may not produce EMG signals of sufficient intensity and may have more noise contamination, which reduces the accuracy of the recognition. The substantial lack of user studies involving older adults makes the performance only statistically significant for young users leaving the results of the performance for older users undefined. As a result two previous limitations may also be highly dependent on this factor.

5. Potential solution

When designing the gesture interface, in general, it is important to understand, categorize, as well as reflect their physical capabilities and aptitude in the design of both the hardware and the software [17]. To better understand and feel the gesture interactions within the environment, using an inductive approach, we developed the gesture-interaction, human-tracking perception system (Fig.1) to control a set of smart-home lights using the MYO Armband in the simulated room environment. The system setup comprised of the Microsoft Kinect (a body skeleton tracker), Myo Armband, and custom software developed to support interaction by combining these devices. Kinect helped to recognize spatial deictic gestures (e.g. pointing at objects). MYO, with its IMU(inertial measurement unit) and EMG sensors on board, allowed measurement of hand orientation in space and the recognition of particular gestures. Together, the devices and software gave us the ability to control Philips Hue bulbs using various continuous and discrete gestures. We successfully developed a system and controlled floor lamps using the MYO Armband, with its simple built-in gestures.

Figure 1. Gesture-interaction, human-tracking perception system. For more details, please, see https://www.youtube.com/watch?v=sBx2zvBriyo

Throughout the implementation of the system, we discovered difficulties using the built-in MYO gestures that are related to EMG sensing, as they require high-level tension movements to work (e.g. clenching a fist), producing fatigue that greatly decreases the accuracy of the device in a short period of time. We reasonably inferred that this difficulty would be magnified when used by people with hand mobility issues, making MYO difficult or even not possible for them to use. The approach of the existing problem we propose lies in a consilience of two areas of research and building a bridge between them by studying the surface EMG devices from both a biomedical engineering and an HCI perspective. Biomedical engineering, as a field, extensively studies the relationship between surface EMG sensors and hand kinematics to improve robotics hand prosthesis, which implies the notion of subtle/fine gestures or movements detection [54]. HCI is more shifted toward studying user groups and the best fit design solutions of the interface of interaction.

There are very few studies in HCI which specifically emphasize the importance of the subtle gesture. Wan et al. built custom hardware combining the EMG sensor with force sensitive resistors[55]. Thus, their system deals with subtle hand movements or the single finger movements as well as the combination of fingers and hand movements with very high accuracy. However, authors never mentioned using their technology as a possible application for older adults. Of particular interest and relation to our research is the work of Abduo et al. [42] as they structured together the medical and HCI purposes of the MYO Armband and looked at this commercial product from the medical viewpoint. Our approach will extend the results of this work by shifting attention to the use of EMG sensors in smart home environments, adapted for a ”weak” hand with mobility issues for purposes of a fine gestural control.

6. Conclusion

This research will provide a number of benefits to both HCI and Health-care communities. As one of the directions of Ambient Assisted Living, this research attempts to explore a technical solution for finer EMG-based hand gestures to accommodate diverse groups of people in our society, including older adults who may require frequent or daily assistance. Our hope to support older adults in living independently with technological solutions is shared by many people worldwide. Safe and comfortable independent living is what many of us in our society desire (e.g., older adults themselves, their family members, and caregivers). We hope our proposed solutions, by using EMG sensors to enable the use of gestures in smart homes, offer a potential support for gradual but meaningful life style changes.

Acknowledgement

We acknowledge a support from our industrial partner Honda Research Institute, Japan. We also thank John Swystun for invaluable comments on our paper.

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