Toward Smart Rings as Assistive Devices for People with Motor Impairments: A Position Paper

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ABSTRACT

In this position paper we highlight the potential of finger augmentation devices, such as smart rings, for designing assistive technology for people with upper body motor impairments. We review the literature on assistive input for motor impairments and point out the fact that no prior work has examined the application opportunities of finger augmentation devices for people with motor impairments, despite vast attention dedicated to other input devices and modalities, such as touch, voice, eye gaze tracking, and direct brain-computer input. To foster explorations of smart rings as assistive devices for users with motor impairments, we recommend several directions of investigation, such as designing one-button or microswitch interactions, design of multi-device user interfaces that combine smart rings with touch input on mobile devices, recognition of mid-air gestures performed by movements of the upper arm and shoulder, and application of the principles of ability-based design for self-adapting smart ring gesture user interfaces to accommodate a wide range of motor impairments.

Author Keywords

Smart rings; Wearables; Motor impairments; Finger augmentation devices; Microswitch; Gesture input; Ability-based design; Position paper.

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation (e.g., HCI)] User Interfaces: *Input devices and strategies*; K.4.2. [Computers and Society] Social Issues: *Assistive technologies for persons with disabilities*.

INTRODUCTION

Finger augmentation devices are represented by sensors and electronic gadgets worn at finger-level and operated by finger and hand movements, such as smart rings [6-8], fingernail displays [41], and numerical gloves [42,43]. Augmenting fingers with input/output capabilities to sense muscle activity, motion, and gestures and to provide localized feedback sets the technological premises for unprecedented synergy between the motor abilities of the human hand and physical-digital computing. However, despite the recent interest in the community for finger augmentation devices in general [1-5] and the remarkable technical features that they bring to mobile and wearable computing scenarios and contexts of use, there has been no exploration so far in the Human-Computer Interaction literature of finger augmentation devices as assistive technology for users with motor impairments. To address this fact, this paper makes a *position statement to encourage scientific exploration of finger augmentation devices, especially smart rings, as candidate input/output devices to implement wearable assistive technology for*

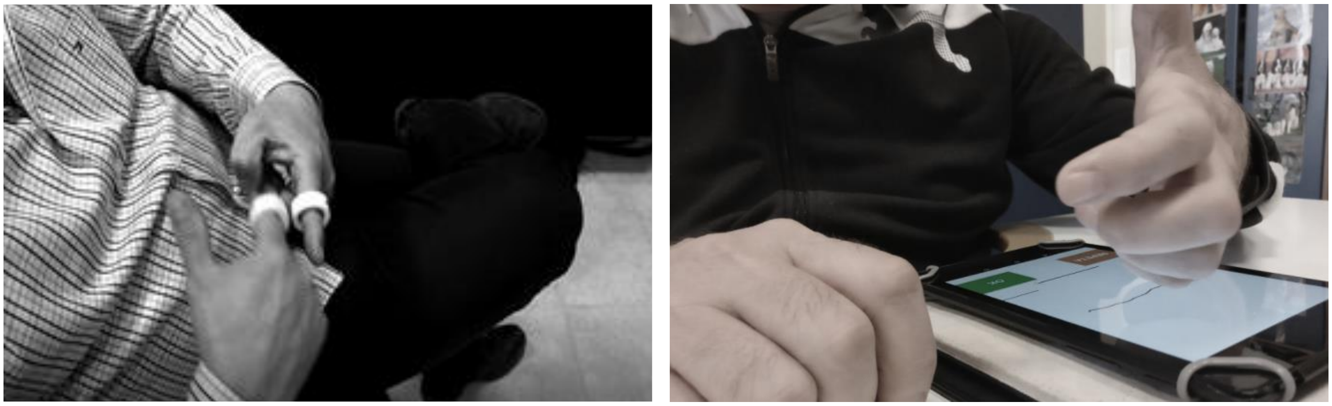

Figure 1. Smart rings embed sensors to detect user input as well as LEDs, buzzers, and vibrotactile actuators to deliver feedback. In the left figure, a user *without* motor impairments performs a complex gesture with two Ring Zero devices [25,26]. In the right image, a person *with* motor impairments (Spinal Cord Injury) adopts a specific hand pose to operate a touchscreen device [45,55]. Unfortunately, the lack of studies regarding finger augmentation devices for motor impairments prevents proper understanding and exploitation of the opportunities provided by smart rings as assistive devices for users with motor impairments.

users with upper body motor impairments. Specifically, our contributions are as follows: (1) we conduct an overview of the relevant literature on finger augmentation devices and we point to the fact that no applications have been considered so far for users with motor impairments and (2) we outline several research directions for inclusive design and assistive input techniques for smart rings and users with upper body motor impairments.

RELATED WORK

In this section, we review prior work on smart rings and summarize the main directions of investigation explored in the community for designing assistive techniques and devices for users with motor impairments.

Smart Rings Technology and User Interfaces

Technology for wearable input devices, including smart rings, has advanced notably in the recent years, especially in terms of miniaturization, communications, consumed power, and battery lifespan. Shilkrot *et al.* [1] classified finger augmentation devices into five categories depending on the device form factor, input type, output action, and application domain. Smart rings incorporate a wide range of electronic components, such as memory, microprocessors, near-field communications chips (NFC), LEDs, vibrating motors and actuators, GPS, and Bluetooth, as well as a rich variety of sensors to detect user input, such as accelerometers, gyroscopes, infrared proximity sensors, microphones, cameras, and heart rate sensors [1]. For example, Ring ZERO [7], illustrated in Figure 1 on the previous page, features a touch button, an orientation sensor, and Bluetooth 4.0 to report data to a connected smart device, such as a smartphone, all embedded in a small form factor with a weight of just a few grams. The majority of smart rings available commercially make use of NFC technology for practical purposes of authentication or processing payments [6]. Other smart rings enable gesture input, either in the form of touch input or finger, hand, and arm movements performed in mid-air. In this direction, Gheran *et al.* [25,26] examined users' preferences for gestures performed with one and two smart rings, reported consensus metrics, and recommended design guidelines for gesture user interfaces for one and two smart rings, such as design informed by temporal calculus [25].

Accessible Input for Users with Motor Impairments

Extensive work has been conducted to propose assistive technology for users with motor impairments. In the following, we review touch, voice, eye gaze, and electroencephalography as representative input modalities considered so far by researchers and practitioners.

Touch input. The past years have led to a prevalence of touchscreen mobile devices, such as smartphones, tablets, and smartwatches, that expose user interfaces operated via taps, swipes, flicks, stroke gestures, and multitouch input. However, touch and multitouch input require dexterous abilities to select targets precisely and slide the fingers accurately across the screen to produce swipes and strokes that a gesture recognizer would interpret correctly. These requirements cause challenges for users with upper body motor impairments, which have been documented in the literature. For instance, Mott *et al.* [9] reported on the challenges that people with motor impairments encounter when acquiring touch targets on large interactive surfaces. They reported empirical data for touch trials that were on average about 10 cm off from the intended targets. By analyzing users' touch patterns, Mott *et al.* [9] proposed an assistive technique called "Smart Touch" based on template matching and a variant of the \$P point-cloud gesture recognition technique [50] to improve the accuracy of target acquisition for users with motor impairments on touchscreens. Findlater *et al.* [44] also reported high error rates on touchscreens compared to mouse input for users with motor impairments and outlined design guidelines and recommendations to overcome such challenges, *e.g.*, increasing touch targets to at least 18 mm in size. "Barrier pointing," a technique developed by Froehlich *et al.* [10], relies on the physical edges of the mobile device to assist touch target acquisition: targets are placed mainly around the edges, while the center of the screen is used for output. Guerreiro *et al.* [12] examined "tapping gestures," an interaction technique designed for users with tetraplegia. Their study revealed that tapping delivers optimal performance for touch targets at least 12 mm in size. Understanding touch input "in the wild," outside the controlled environment of laboratory testing, has also been given attention. In this direction, Montague *et al.* [13] conducted a four-week's study with nine users with motor impairments and documented their touch input patterns and performance. Results showed that performance varied significantly not only between participants, but also within the same participant over multiple sessions. Another investigation related to the accessibility of smartphones for users with motor impairments revealed contextual challenges and important situational impairments related to using wearable devices in real-world conditions [30].

Eye gaze input. Eye gaze tracking represents the process of detecting, tracking, and mapping the movements of the user's eyes to a computer screen. The process is based on the optical tracking of corneal reflections to assess visual attention. Because only eye movements are required, eye gaze input represents a viable option for assisting users with motor impairments to interact effectively with computer systems. Consequently, eye gaze tracking has been examined thoroughly in the assistive technology community for various applications, such as design according to necessities [14], enabling self-expression [15], text input [17], or adaptation techniques for graphical user interfaces, such as mapping eye movements to the position of the mouse cursor on the screen [16].

Voice input. Voice input, in the form of natural speech, word commands, or paraverbal input, represents a suitable assistive input technique for users with motor impairments that has been examined extensively in the community. The "vocal joystick" of Bilmes *et al.* [18], for example, implemented a wide range of acoustic-phonetic parameters, since even spoken commands can be challenging to produce for some types of motor impairments. Mobile devices have also started to incorporate support for voice input. The "Mobile Voice User Interface" [19] is one such example designed to provide a high level of accessibility and independence for users. The many voice-based applications that were proposed and validated in the community, such as "VoiceDraw" [20], "Programming by Voice" [21] or voice-based game controllers [22], to name just a few, support voice as a key input modality to implement assistive techniques for users with motor impairments.

Brain-computer interfaces. Yet another direction explored in the assistive technology community revolves around brain-computer interfaces (BCI). Brain-computer user interfaces operate based on signal processing and machine learning techniques that are used to analyze and interpret electroencephalography data (EEG). Applications of brain-operated computers were proposed and evaluated for people with upper-body motor impairments for rehabilitation [23] or palliative care [24]. Today, several commercial BCI devices are available at reasonable prices that provide direct access to raw EEG data, but that also compute aggregated measurements from the electrical activity of the brain, such as estimates of short-term excitement or frustration levels [52]. While still not completely satisfactory in terms of accuracy and reliability, great potential is envisaged for practical applications for accessibility with visions outlined by Facebook's typing-by-brain project [37] or NeuraLink's neural implants [38].

Wearable Assistive Technology

Wearable technology brings the great promise of extreme mobility and efficient interaction on the go: user input is conveniently sensed by devices that are worn rather than held, which frees up the hands for other tasks. At the same time, output and feedback can be localized on the user's body, such as on the wrist for smartwatches, on the forearm for armbands, or at finger level for smart rings and other finger augmentation devices. However, current designs of wearable technology are not inclusive and, consequently, interaction challenges have seldom been reported for users with motor impairments. For example, while evaluating a head-mounted display originally developed for hands-free interaction, Malu and Findlater [27] reported the need for alternative means of control for users with motor impairments, since half of their participants had difficulties operating the head-mounted display effectively. Wearable touchpads were proposed as an alternative input modality, for which the size and placement were recommended to be adjusted to the specific motor abilities of each individual user [27]. Other studies [28,29] revealed that head-mounted displays can be a viable option for accessible health and fitness tracking applications for people that are unable to interact with touchscreens.

A Short Overview of Upper Body Motor Impairments

Before moving further, we believe that a short overview of the primary types and causes of motor impairment may be beneficial to understand the potential of finger augmentation devices for this user category. The specificity of interacting with a computer implies, in the majority of cases, the use of hand movements to operate various input devices, *e.g.*, keyboard, mouse, touchscreen, joystick, etc. The motor activity of the interaction involves movement with the purpose to reach some target, which may be a key or a button, an option in a menu, controlling the slider of a scrollbar, selecting a portion of text, and so on. Movement occurs either in a 2-D plane (*e.g.*, is restricted to the screen where the cursor lies) or in 3-D (*e.g.*, when pressing a button on the keyboard, moving the finger toward a touchscreen, or manipulating a joystick). For people with upper body motor impairments, performing hand and finger movements to produce an optimal trajectory toward targets or forming stable hand postures (*e.g.*, the index finger stretched) pose considerable challenges.

A motor impairment is a diminished ability of a person with direct implications on their mobility, coordination, balance, neurocognitive capacity, communication, and orientation, caused by a medical condition of the central or peripheral nervous system. Causes of motor impairments are either acquired during lifetime or an effect of a genetic condition:

- *Acquired motor impairments*, such as those caused by spinal cord injury (SCI), result in paralysis of the lower or upper body limbs. Spinal cord injury affects around 270,000 people in the United States alone [33], while brain injuries reached 8.5% of the population in what has been coined as the "silent epidemic" [46]. In Europe, the incidence of traumatic brain injuries is 235 per 100,000 persons, mainly of which are males between 15 and 24 years old [47]. Cerebral palsy is the most common motor impairment among children and is caused by damage to the brain in the prenatal period.
- *Genetic conditions* of motor impairments include muscular dystrophy, multiple and lateral sclerosis, and arthritis. Multiple sclerosis affects 2.1 million people worldwide [34] and arthritis has a 22.7% incidence rate. Clinical manifestations include paresis (*i.e.*, loss of muscular force), plegia (*i.e.*, severe affectation of the muscular force with a loss of contractility), disturbances of coordination, language, and speech, and various other sensorial or neurocognitive disorders.

Summary

A lot of work has been conducted in the assistive technology community to enable people with motor impairments to interact effectively with computer and information systems by means of touch, voice, eye gaze, or direct brain-computer input. At the same time, we are witnessing an increasing growth in miniaturized wearable devices and gadgets, such as smart rings, smart bands, and smart jewelry, with many commercial products available on the market. In their extensive survey on finger augmented

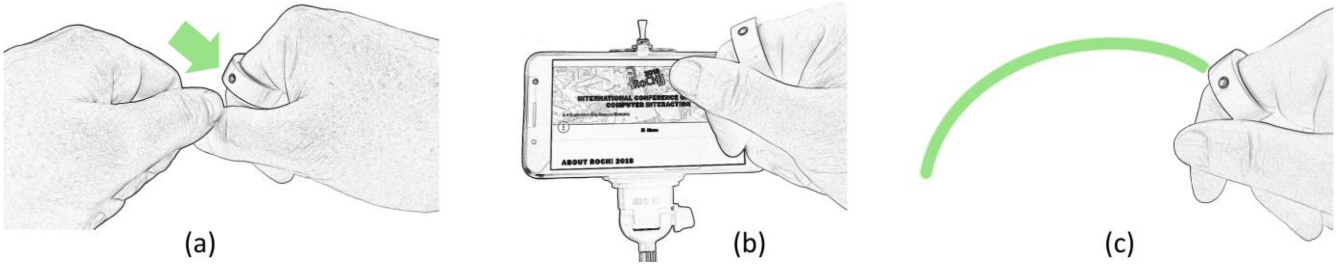

Figure 2. Recommended explorations of smart rings as assistive devices: (a) one-button interactions, (b) joint interaction design between smart rings and mobile devices, such as smartphones, and (c) recognition of mid-air gestures performed by arm and shoulder movements.

devices, Shilkrot *et al.* [1] remarked that the majority of work in accessibility computing and wearable devices has addressed people with visual impairments, such as the "EyeRing" [2,3] or "FingerReader" prototypes [4,5], while for other categories of impairments a very limited number of studies exist to date. Unfortunately, the potential of smart rings for people with motor impairments has not been examined so far. *We believe that it is high time to explore this direction, and this paper represents both a position and an argument to foster such developments in our community.*

TOWARD FINGER AUGMENTATION DEVICES FOR PEOPLE WITH UPPER BODY MOTOR IMPAIRMENTS

Research on finger augmentation devices and upper body motor impairments is unfortunately lacking. However, smart rings have started to be commercially available, with features that mediate a wide range of mundane interactions in the real-world, such as making payments, gaining access to facilities, receiving notifications, and controlling appliances for smart home contexts of use [6,39,40]. Unfortunately, because of a lack of studies and explorations in the community, we are unaware of the effectiveness and potential of smart rings to provide assistive input for people with motor impairments. Based on the available literature and our experience and insights, we can recommend several interesting and promising directions for future exploration:

❶ ***Design "one-button" interactions for smart rings.*** Smart rings usually embed some form of a binary input sensor, such as a physical or a touch button. The Ring ZERO device [7], for example, features a button that reports both short (*i.e.*, less than two seconds) and long presses; see Figure 2a. A mere button with just two states may not seem as much, but prior work has shown how complex tasks can be achieved with one button only, given proper interaction design. A special genre of computer games, known as "one-button games" [31], enables users to perform complex interactions with mere presses of a single button. For example, "Miami Street" [53], a car racing video game just launched in 2018 can be played with mouse clicks only by following the on-screen instructions, such as "hold left mouse to accelerate" or "release to break." A similar example revolves around the concept of a "microswitch" [36] that has been implemented with a variety of modalities, sensors, and devices to enable assistive technology for people with motor impairments. For example, Lancioni *et al.* [32] documented the case of two people with severe post-comma motor impairments and showed how they benefited from microswitch assistive technology. Also, sequences of binary input, including rhythmic beats known as "tap songs" [35], are possible with just one button, where a sequence of n taps can effect up to 2^n distinct commands. Tap input is straightforward to achieve with smart rings and, consequently, the smart ring microswitch should be investigated. Also, multi-tap input is especially appealing for two smart rings that can be worn on both hands [25], for which input can be synchronized or microswitch taps designed to follow various temporal patterns [26].

❷ ***Joint interaction design for smart rings and personal mobile devices.*** Prior work has reported on the many challenges encountered by users with motor impairments when performing standard tasks on touchscreens, such as acquiring targets [9,13]. Joint use of smart rings, featuring one-button interactions (see previously) or mid-air gestures (see next), and mobile devices should be explored to enable users with upper body motor impairments with multiple options to perform tasks on their mobile devices (Figure 2b), such as making or answering calls, launching and closing apps, receiving notifications, or effecting generic commands. We thus recommend exploration of multi-device input designs that include smart rings.

❸ ***Exploration of mid-air gesture input.*** Prior work on gesture input for users with motor impairments has been restricted to either touch input [9,30] or stroke gestures on touchscreens [45]. Ungurean *et al.* [45] showed that people with upper body motor impairments need to use a variety of coping strategies to be able to enter stroke gestures on touchscreens. The resulted gesture shapes meet the quality motor criteria of the Kinematic Theory, as reflected by performance metrics, such as the signal-to-noise ratio or the log-normality principle [45,55]. These prior results encourage examination of other gesture types for people with motor impairments, such as mid-air gestures; see Figure 2c. Even for severe injuries (SCI), motor impairments mostly affect the movements of the fingers alone, while the upper arm and shoulder can still move to perform various tasks, such as to control wheelchairs, reach to shake hands, push and manipulate objects. Smart rings can detect mid-air gestures via embedded accelerometers and gyroscopes, while pattern recognition algorithms are available to recognize those gestures effectively [48] or can be tuned to match the specific gesture articulation characteristics of a given category of users [54,56]. Nevertheless, mid-air gesture input has not been examined for users with upper body motor impairments, despite the advances in and prevalence of mid-air gesture and motion sensing devices, such as smartwatches [57], the Leap Motion controller [58], the Myo armband [59], or the Microsoft Kinect sensor [60], to mention just a few of the best known ones. Smart rings embed accelerometers and gyroscopes and, consequently, can sense and report arm and shoulder movements accurately. We thus recommend exploration of mid-air gesture input enabled by smart rings and analysis of mid-air gesture performance for users with motor impairments.

❹ ***Ability-based design for smart ring user interfaces.*** A sensible design approach to accommodate a diverse range of impairments is to propose interactive systems capable of adapting to specific impairments and automatically generate the most suited form of the user interface [11]. SUPPLE and SUPPLE++ [11] represent instances of ability-based design [49]. SUPPLE is based on a preference elicitation engine, while the adaptation of the user interface is done indirectly. SUPPLE++ adapts to the user's needs by informing on the results of a calibration procedure. Ability-based design inspires design of assistive technology by focusing on users' abilities rather than disabilities [51]. We recommend the application of ability-based design principles for user interfaces for smart rings, such as gesture sets that adapt to specific motor impairments, or microswitch and one-button interactions suited to the motor abilities of each user.

CONCLUSION

Assistive technology can improve the quality of life for people with motor impairments. Even for severe brain or spinal cord injuries, degenerative diseases, or for people with multiple disabilities (*e.g.*, motor, visual, and/or speech), assistive technology has been shown to change their life from passivity and isolation to integration. The right combination of software and electronics already enable people with motor impairments to use the Internet, write, play video games, make and receive phone calls and, thus, improves the quality of their social life. The dawn of the wearable computing era brings even more potential for assistive and inclusive design. Smart rings, especially, can instantiate into effective implementations of the popular microswitch approach. With the general availability of wearable devices and gadgets and an expected increase in market demand for the next years, we expect more advances to enhance the life of people with motor impairments. We hope that our position paper, identifying an important gap in the scientific and applied knowledge in the community, will foster new investigations, inform new designs, development, and evaluation of smart rings as assistive devices for people with motor impairments.

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