Smart Fingers: Devices for Assistive Pointing Augmentation

PhD Proposal

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Approved by the
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Executive Summary

Problem

How can finger augmentation technology help us gain new skills or recover lost ones? Wearable devices that deliver special abilities are a mythical intercultural desire reflected in both traditional and modern narratives. Now, with the advent of ubiquitous computers, we can embed technology in existing and new hand-augmenting objects to support their innate operation and enable novel uses. My research focuses on the following questions derived from this vision: How can we create hand-wearable tools that assist manual operations through technological augmentation? What kind of assistance can these tools offer in acquiring new skills and regaining lost skills? What are the design considerations for such augmenting devices?

Approach

Sensorial incapacity, capacity and "ultra-capacity" may be considered as a continuum of usability, rather than as extreme points of focus for technology developers. The spectrum of Assistive Augmentation technology, which begins at tailored solutions for persons with special needs and ends in human magnification (see Fig. 1 on page 4), guides my research. I present two projects that exemplify this idea: EyeRing and FingerReader. The EyeRing and FingerReader are finger-wearable assistive devices, equipped with a camera, that are used for retrieving information as well as reading alphabetic and symbolic languages, even for people with impaired eyesight. The work draws from theory and practice in human-computer interaction (HCI), assistive technology, human augmentation and augmented reality (AR).

Contributions

The work will present a conceptual framework for assistive pointing augmentation consisting of a comprehensive survey, a terminology and a set of guidelines for future work in designing such devices. The thesis will contribute new designs of finger-worn devices that augment their operator's pointing gesture via computerized sensing, control and feedback. Further, it will include user studies with the target audiences that show the feasibility of the design approach and the specific implementations in a real-world scenario.

Contents

Introduction

Motivation

Stories and legends abound with hand wielded objects whose capabilities extend beyond their native performance. Moses' staff, Thor's hammer, King Arthur's Excalibur, and Sauron's rings are all archetypes of devices that empower their possessors. These often have intelligence and purpose of their own and perform in a unique, extended quality that far surpasses the standard object of their kind. They reflect cultural narratives of technology and its limitations, contrasting technical appearance with fictional capabilities.

Recently, a dream come true has become evident: digital technologies that enable augmentation of hand worn devices, creating new capabilities and interactions. With or without impairments, people find themselves at the edge of sensorial and manual capability and seek assistive or enhancing devices. The overarching topic of the thesis proposed here is centered on the design and development of assistive technology, user interfaces and interactions that seamlessly integrate with a user's mind, body and behavior, providing an enhanced perception and motor control. I call this "Assistive Augmentation".

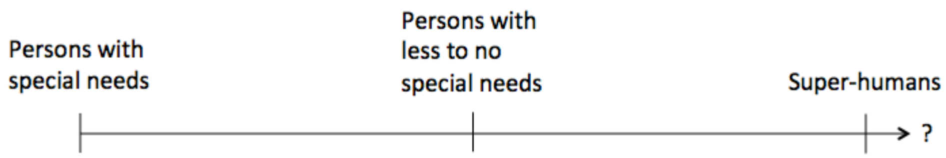

Figure 1: Assistive Augmentation continuum.

Assistive augmentation finds its application in a variety of contexts, for example in providing a scaffold for people when they feel their innate senses are inadequate or to support development of desired skillsets. I wish to put sensorial ability and disability on a continuum of usability (see Fig.1), rather than treat one or the other extreme as the focus. I therefore follow the design rationale of Rekimoto [1] stating technology should be socially acceptable, work coherently for people with and without impairments alike, and support independent and portable interaction. The latter requirement challenges both user interface and interaction design in particular, as Jones and Marsden point out: "the test comes when it [the device] is deployed in the complex, messy world of real situations [...] when it has to be used in the wild, as it were, in tandem with the world around it, the usability can break down quickly" (cf. [2], p. 51).

Approach and Theoretical Grounding

> “The future of interaction lies not in the interface ’disappearing’,
> but rather in the interface becoming even more visible”
> – Paul Dourish, Where the Action Is

My work draws on lessons from the Third Paradigm of HCI theory [3], in particular that of Ubiquitous Computing and of Embodiment, both products of the HCI theorists of the 1990s. An especially interesting hypothesis, set forth by Paul Dourish, concerns the relation of interactive technology and human perception of the world. Dourish opens his book "Where the Action Is" by stating how in the dawn of modern computing, when computers were scarce and incredibly expensive, the computer’s time was far more valuable than the user’s time, and how this formed the concept of making the job easier for the computer and harder for the user [4]. Whereas today with contemporary computers, the balance should be different – computers must be highly responsive to the user’s actions and needs.

The core of Dourish’s ideas is embodiment, what he describes as "being manifest in as part of the world", a well established theory in the area of phenomenology, developed by Edmnud Husserl and Martin Heidegger in the first half of the 20th century. Interaction is an embodied action, meaning it moved from being an idea in one’s mind to an experience in one’s hand. An obvious connection of assistive augmentation to embodiment is the fact that sensorial augmentation, as is perception, is embedded in the real environment. In many cases the augmentation is mediated, as in the case of screens and cameras, but the constant central element is an embodied augmentation of a human sensory experience.

Dourish developed the idea of the importance of the human body and environment to computer interfaces stating that every activity is situated in and derives meaning from a particular environment and a moment in time, in addition to that, human understanding of the world stems from the ability to act within it and upon it, rather than only observe and contemplate it.

Ubiquitous Computing (UbiComp) is a concept of the future of HCI set forth by Mark Weiser [5] and Pierre Wellner [6]. Weiser defines UbiComp as an embedding of computers in everyday objects and the environment itself: walls, notepads, pens and even doors. Weiser’s goal in UbiComp was to make technology invisible, and he also claims that indeed in Virtual Reality the computer is effectively invisible [7]. Nicola Liberati, a contemporary phenomenologist of AR and UbiComp, imparts a central guideline to the creation of "good AR" technology: augmented objects should be as perceptually real ones so that the technology itself would seem invisible, while UbiComp is not an enhancement of the *subject* like AR but of the *objects*, it shares the same goals as AR of exposing a clear affordance to the user [8].

These theorizations guided my work towards devices that offer augmentations directly of the hand of the user. The computerized elements augment a well-practiced deictic gesture of pointing a finger. An important component of embodied interaction, according to my interpretation, is that the user must always remain in manual control of the action, to maintain the percepted integration of mind, hand and computer.

Assistive Pointing Augmentation as a Conceptual Framework

> “there isn’t one preferred interpretation of a system but multiple. [...] technologies are *interpretively flexible*, i.e., lend themselves to different interpretations besides those intended by their developers”
> – Yvonne Rogers, HCI Theory

The thesis will conceptualize a framework for Assistive Pointing Augmentation (APA) to be used for organizing my own work, but may also offer other researchers a basis to build on in their work. According to Yvonne Rogers, a conceptual framework in the field of HCI, as opposed to a *paradigm*, *theory* or a *model*, is a set of core concepts, questions and principles to consider when designing novel user interfaces ([9] p.5). APA focuses on the domains of hand and finger augmentation with purpose of augmenting the pointing gesture.

As mentioned earlier, the core concept of APA is that assistive technology can most times apply outside the intended targeted assistance modality, therefore it creates a continuum of usability rather than hotspots or extremes. For example, if we consider depth cameras as a technology, their conception was in the robotics domain, however recently they moved to the computer interaction domain (e.g. in the Kinect), and already there is a myriad of examples of how they can revolutionize the area of assistive technology for persons with visual impairments [10]. APA hints that practically any human-facing technology is in fact assistive technology, and the level of assistance for a certain audience depends on the primary intention of the creator, but it need not be so. The notion of the flexibility of technology to be applied to uses other than the intention of the creator is already an existing discourse in the HCI community ([9] p.71).

APA will be developed in the thesis as a descriptive, prescriptive, generative and ethnographic ([9] p.16) framework, thus it will provide:

- a terminology for researchers to speak about cross-boundary assistive wearable technology;
- guidelines for technology designers to contemplate impact on, or at least consideration of, using their proposed technology in additional application domains;
- help for creators to generate novel uses for a technology they developed with a specific use in mind;
- accounts of laboratory and in-the-field user studies with the target-audience that test validity of the proposed interactions.

Related Work

The new work presented in the thesis focuses on augmentation of the fingers via finger-wearable devices. This section will cover the relevant work in this domains, and a much broader discussion will be presented in the thesis itself.

Finger-worn Devices

Finger-worn interaction devices received noteworthy attention over the last few years from HCI researchers [11] and user experience designers alike [12, 13]. Explorations of finger-worn interaction devices may be divided into a number of categories according to how they are operated, as illustrated in Fig.2. Augmented finger gestures include (1) Pointing [14, 15]; (2) Tapping/Touching [16, 17, 18]; (3) Gesturing [19, 20, 21]; (4) Pressing/Clicking On-Device [22, 23, 24].

Remotely controlling objects in the environment by pointing with a wearable device was implemented in the Ubi-Finger [15] project. Efforts to attach and retrieve information from physical objects were implemented in [14] and recently in [18] using IR beacons and coded textures. However these

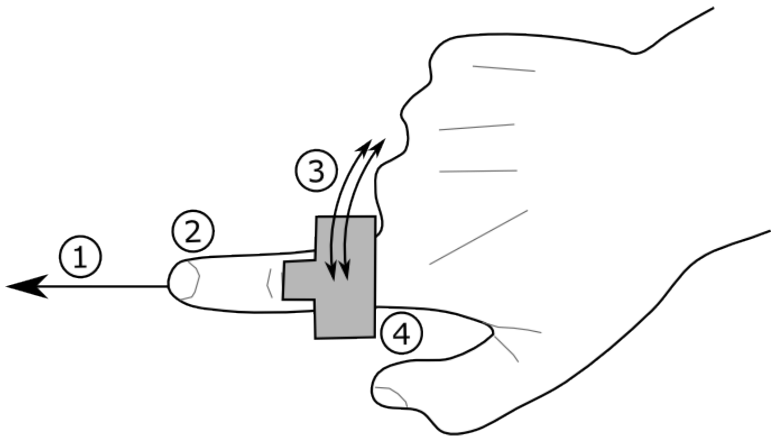

Figure 2: Types of finger-worn device actions. (1) Pointing. (2) Tapping. (3) Gesturing. (4) Pressing.

applications often require the environment to be instrumented with sensors and markers, which limits the interactions to instrumented environments.

Generic multipurpose finger-worn input system were suggested by Chatterjee and Fumtoshi [22] who developed a device based on capacitive sensing, and more recently by Ogata et al. [24] who achieved the same with infrared sensors.

In the thesis I plan to present a comprehensive taxonomy of over 100 academic projects, products, patents and published concepts of finger augmentation devices (see Fig. 3). It will provide a methodical system for categorizing the work with an abundance of corroborating examples, as well as point to under-explored areas of the design space to offer new research opportunities.

Proposed Research

The EyeRing and FingerReader

The pointing gesture is fundamental to human behavior and used consistently across cultures [25]. It is a natural and universal deictic gesture [26] in our gestural language, are inherently used for interaction, by letting us reference proximal and distal objects as well as abstract concepts in the world. EyeRing and FingerReader augment this natural behavior without obstructing it, instead they leverage the attributes of the pointing gesture as guides for

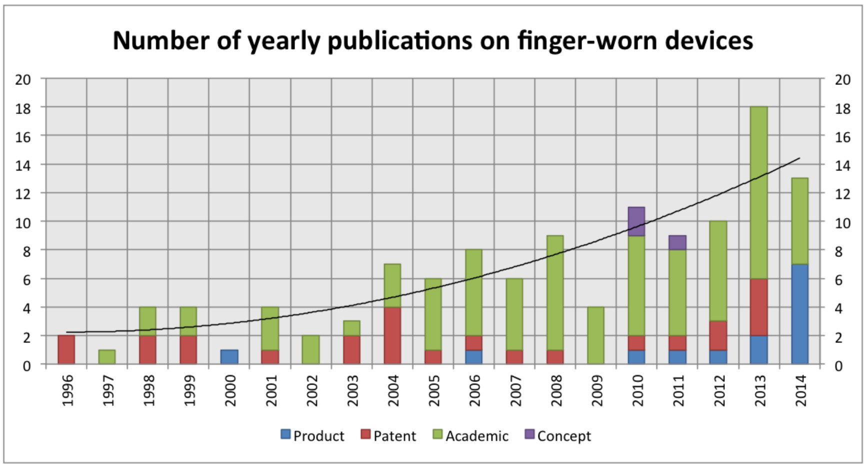

Figure 3: Yearly publications on finger-worn devices. A total of 128 items. Note: 6 more publications in the years 1977-1994 are not visualized here.

the device to support the embodied interaction: focus of attention and the implied dialog between the user and the object.

The applications we developed for the EyeRing and FingerReader revolve around three major themes: assisting people with visual impairments to access visual information, reading symbolic languages and general purpose usage. The assistive applications are: recognizing colors, reading barcodes and recognizing currency [27, 28]. Reading printed text was recently developed with the FingerReader [29], and reading music sheets is yet unpublished work. Our collaborators in the Singapore University of Technology and Design contributed additional work on the EyeRing with interfaces for finger-painting [30] and general purpose interaction with objects [31], which join our own efforts to create a method intended for interaction with a PC [28].

Creating hand-wearable augmenting devices

My proposed research will focus on the following questions:

- How can we create finger-wearable devices that assist manual operations through technological augmentation?
- What kind of assistance do the tools I've created offer in acquiring new skills and regaining lost skills? and how do we obtain the right balance between computerized assistance and manual freedom?

Figure 4: EyeRing and FingerReader applications, clockwise from top-left: recognizing currency, reading price tags and barcodes, copy-paste into virtual documents, reading sheet music, and reading printed text.

When considering new devices for finger-based augmentation I can distinguish the following categories of design considerations:

- How does the device use the anatomy of the finger? (innate finger senses, finger movement, location on the finger, multiple fingers, consideration of the hand)
- Does the device use a well practiced behavior or gesture? does it rely on proprioception or hand-eye coordination?
- Does the device use the ring as an object of fashion and history as jewelry?
- How does the device achieve a comfortable and usable design? in terms of sizing, wearing and removing with ease, placing of buttons, sensors and outputs.
- Does the device have companion devices? Is the device itself a companion device to others?
- How does the user interact with the device? is it inconspicuous and private or is it public and social? What are the feedback and input modalities?

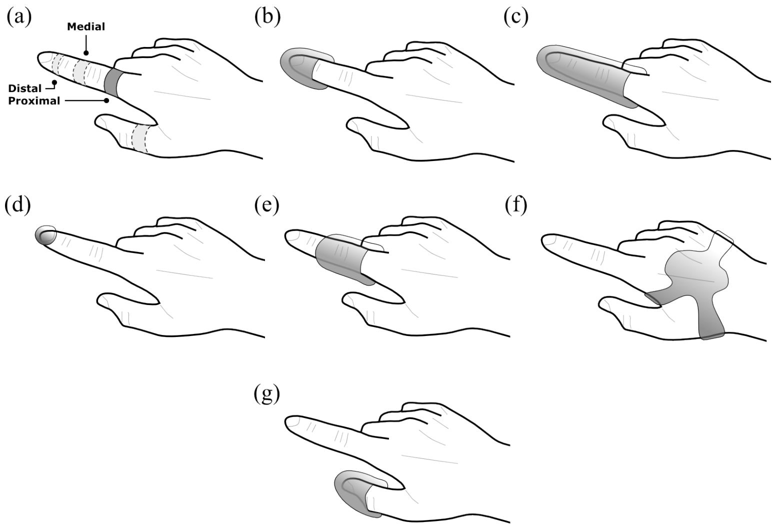

Figure 5: Finger-worn devices typical form factors. (a) rings, (b) distal addendum, (c) whole finger addendum (d) fingernail addendum, (e) sleeve, (f) palm component that accompanies an FAD, (g) thumb addendum. EyeRing and FingerReader are type (a)-proximal/(e).

- Is the device targeted to a specific audience as assistive technology?

In part, my work focused on using camera-based sensing technology and computer-vision algorithms to analyze the visual data. Nonetheless, cameras and a wide range of other types of sensors were already used in finger-based devices, as can be seen in the related work section and will be discussed in much more detail in the thesis itself. The choice of a sensor technology is derived by the application, which in my case is assistive augmentation with a special interest in two distinct domains: assistance for persons with special needs in visual perception, and devices for computer-assisted manual operations.

Wearable and handheld cameras are ubiquitous in the domain of assistive technology for individuals with visual impairments [10, 32]. Examples range from head and waist mounts, hand-held, hand-worn cameras, and algorithms for virtually countless ways of analysis exist: text [33], scene [34], social [35], navigation [36] and many more. My work focused on finger-wearable cameras for assistive applications [28, 27], dealing in particular with the problem of reading printed text [29].

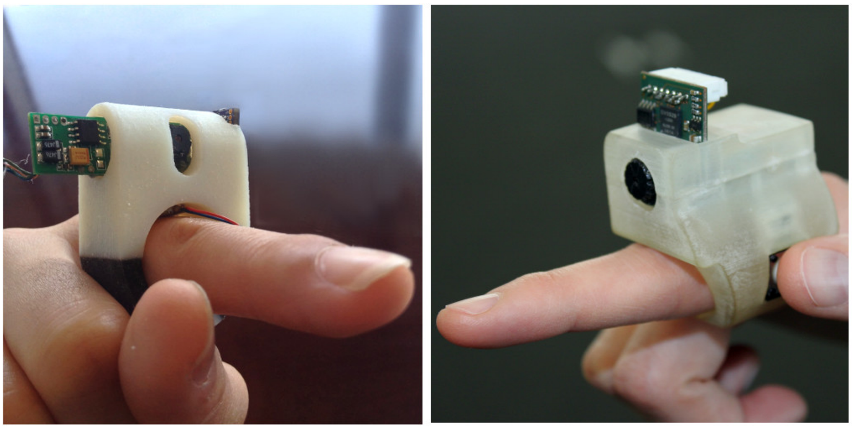

Figure 6: Assistive devices: FingerReader and EyeRing

Research Plan

Expected Contributions and Results

The work will present a taxonomy and conceptual framework for assistive pointing augmentation, in the form of a terminology and a set of guidelines for future work in designing such devices. A methodical survey of prior work, to be presented in the thesis, covers more than 110 examples from the past 30 years of academic, industrial and conceptual work on finger augmenting devices (FADs), and draws out an organizational framework to classify new work in the field. Aside from the scholarly contribution, it also provides an exemplified definition and boundaries for the field of finger augmentation.

The thesis will contribute new designs of hand-worn and hand-held assistive augmentation devices: EyeRing and the FingerReader. I will present the account of their inception and creation, with lessons learned from the design iterations. The thesis also will include reports of user studies that show the feasibility of the approach and the specific implementations in real-world scenarios.

Evaluation: Methods and Practice

The experiments and studies will be designed according to standard methods in the HCI community [37] as well as the investigative psychology community [38]. Work on the EyeRing is mostly concluded, however the FingerReader still requires more formative and summative evaluations.

Current and Future Studies

In addition to the studies already completed (reported in [28, 27, 29]), I plan to hold the following formal evaluations:

- FingerReader
    1. FingerReader study with people with a vision impairment - concluded in Singapore, results are summed in a paper submitted to CHI 2015.
    2. FingerReader study with language learners, in collaboration with the Tufts University Center for Reading and Language Research. To be conducted during Fall semester 2014.
    3. FingerReader study with reading music sheets, in collaboration with the Berklee College of Music Assistive Music Technology program. To be conducted during January 2014.

Many informal evaluations of the FingerReader and EyeRing were also performed throughout the process of creation. These are planned to be reported in journal paper that will provide the basis for one chapter of the PhD thesis.

Resources Required

Since much of the prototyping was already done, not many resources are still needed. However, I will require additional funds for: compensation for study participants, prototyping extra iterations on the FingerReader: a number of 3D-printed elements and a few other electronic components, travel to upcoming conferences

Timeline

See Fig. 7.

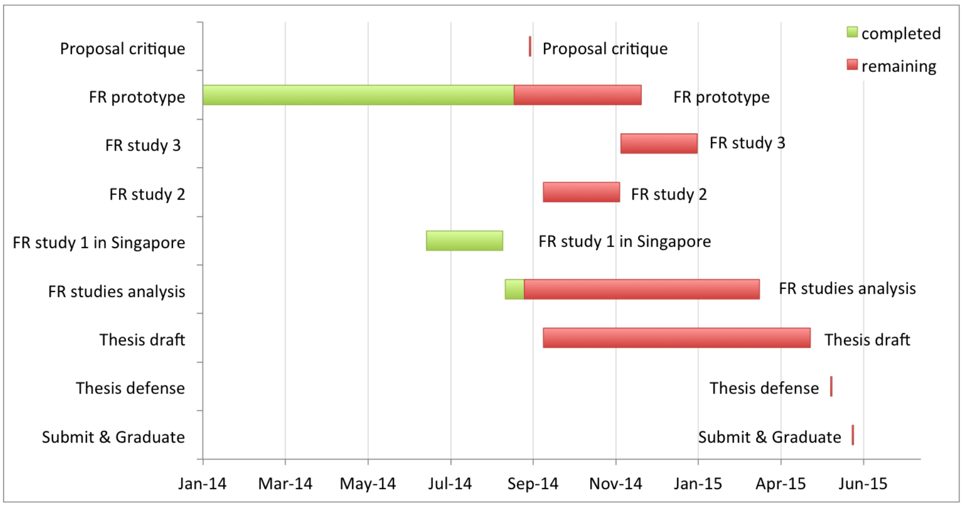

Figure 7: Thesis completion timeline.

Roy Shilkrot - Bio

Figure 8: Hi.

Roy is a PhD student in the Fluid Interfaces group of the MIT Media Lab. His interests are in augmented user interface, sailing, music, writing and language. He recieved a B.Sc in Computer Science from Tel-Aviv-Yaffo College and M.Sc in Computer Science from Tel-Aviv University. He has 8 years experience working in Israeli high-tech industry, both in start-ups and enterprise, and as an intern in Microsoft Research in Redmond WA and Steelcase Inc. in Grand Rapids MI. Prior to the MIT Media Lab he worked in Comverse Innovation Labs, researching and designing mobile user experience.

Appendix: Ken Perlin - Bio

Kenneth H. "Ken" Perlin is a professor in the Department of Computer Science at New York University, founding director of the Media Research Lab at NYU, the Director of the Games for Learning Institute, and also directed the NYU Center for Advanced Technology from 1994 to 2004. His research interests include graphics, animation, multimedia, and science education. He developed or was involved with the development of techniques such as

Perlin noise, hypertexture, real-time interactive character animation, and computer-user interfaces such as zooming user interfaces, stylus-based input, and most recently, cheap, accurate multi-touch input devices. He is also the Chief Technology Advisor of ActorMachine, LLC. Perlin received his Ph.D. in Computer Science from New York University, and a B.A. in theoretical mathematics from Harvard University. [2].

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